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REAR-END TRAIN MARKER LIGHT EVALUATION

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FINAL REPORT

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16. Abstract

All rear-end train marker lights until recently were incandescent bulbs of almost identical design. With the advent of cabooseless trains and battery-powered end-of-train devices, new technologies using low-power LED and xenon flash tube lights were developed. Because of uncertainties in off-axis light intensity distribution, the FRA sponsored this research study to evaluate different types of markers in the context of current Federal regualtions (CFR Part 221).

Laboratory tests were conducted on the train rear-end marker devices from four manufacturers. These included incandescent bulbs, LED arrays, and two different xenon flash tube devices. Both red and amber lenses were tested on two of the devices. Chromaticity (color) measurements were made over a range of 380 to 780 millimicrons wavelength. Peak intensity measurements were then made using a telephotometer at distances of 25 and 100 feet, both at the geometric center and up to ±90 degrees vertically and horizontally from center. Effective intensity values were calculated based on time integration of the pulse shape, using standard IES formulae.

A field test was then conducted to assess the visibility to human observers of the test markers differing in lamp type, color, cycle (pulsed or steady) and intensity. Both subjective assessments and visual detection data were collected, using a population of 24 volunteers. Tests were set up on a 1000-ft stretch of dark road at Battelle's West Jefferson facility. Point of angular detection was measured by slowly rotating each device. On-axis assessment was done by an "A-B" comparison of different marker combinations. Field test data did distinguish among markers.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

PREFACE

Battelle wishes to acknowledge and thank the four manufacturers who contributed rear-end marker devices for use in this study: Dynamic Sciences Limited; Pulse Electronics, Inc.; Star Headlight and Lantern Company; and Transit Control Systems.

The authors wish to acknowledge the many people who contributed to this effort. Thanks to Mr. Garold Thomas, FRA's COTR, and Mr. Howard Moody (formerly of the FRA) for their technical assistance and contributions. Thanks also to Mr. Ernest ("Corky") Dykeman of ETL Laboratories for helping to "sort things out".

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Messrs. Donald Ahlbeck, Denwood Ross, Jim Dye, and Doug Erwin, all of Battelle, provided administrative and technical support for which sincere thanks are extended. Dr. Girard Levy, Battelle, contributed substantially to development of the methodology used in this study and provided useful editorial comments on this final report for which we are grateful. Finally, the authors wish to extend thanks to all the people who participated in the late-night test sessions.

EXECUTIVE SUMMARY

Laboratory Tests

Laboratory tests were conducted on the train rear-end marker devices from four manufacturers. Chromaticity (color) measurements were made for each device to determine irradiance versus wavelength over a range from 380 to 780 millimicrons. Peak intensity measurements were made using a telephotometer at distances of 25 and 100 ft, both on the geometric center and up to ±90° from this center on the horizontal and vertical axes. For the pulsed lamps, effective intensities were calculated from peak intensities and integrating the pulse shape versus time, and using the appropriate formula from the IES Lighting Handbook.

Results from these tests showed that all units met the FRA color range requirements. For the slower pulsed units (Pulse, Star -- typically a 1/4 second pulse duration), peak intensities on-axis exceeded the FRA minimum of 100 candela. Off-axis (±15° horizontally, ±5° vertically), the Pulse devices fell near or below the FRA minimum of 50 candela; while the Star devices (particularly with the amber lens) exceeded the minimum. Effective intensity for these units (in candela-seconds), based on the IES formula, fell below the given minima, except for the Star units with amber lenses.

For the xenon flash tube devices (DSL, TCS -- typically a 20 micro-second pulse duration), peak intensities exceeded the FRA maximum of 1000 candela. Effective intensities for the DSL units exceeded the FRA minimum of 100 on axis, but fell below the FRA minimum of 50 off axis. Effective intensities for the TCS units fell below 1.0, a factor greater than 100 below the FRA minimum.

Comparison of these results with the results from tests conducted by ETL Testing Laboratories, Inc., on the same or similar devices showed that Battelle's peak intensity measurements were substantially lower than ETL's. Direct comparison of measurements with both sets of equipment on three of the devices, using the same set-up procedures, showed good correlation between results. Based on this comparison, we conclude that the major differences in intensity values are the result of device mounting procedures. Where Battelle chose the geometric center of the device for its measurements, ETL chose the lamp "hot spot" (point of maximum inten-sity) for its readings. In future testing, the device mounting protocol must be taken into consideration so that consistency in results may be achieved.

Field (Human Factors) Tests

A field test was conducted to assess the visibility to human observers of a sample of rear-end train markers differing in lamp type, color, cycle (pulsed or steady) and intensity. Both subjective assessments and visual detection data were collected. The following is a summary of results and conclusions with respect to visibility of the markers tested:

1. All markers used in this field test afforded adequate off-axis detection, under the conditions of the test, using the 1000 ft track stopping distance criterion;

2. All markers used in this field test were visible to all subjects in a 1000 ft on-axis viewing condition which simmulated an approach on tangent track;

3. Field test data did distinguish among markers, despite the equality of markers with reference to an acceptable/unacceptable threshold for affording at least 1000 ft of track stopping distance upon detection during a 15-mph slow approach.

4. Markers were ranked in order of off-axis detectibility. The Star units had detection angles from 155° to 164°. All other units had detection angles from 84° to 91°. All were detectable within the desired minimum viewing angle of 57°.

5. Using the off-axis detection test conditions, Star markers were far more readily detected than any of the other makes. When corrected for the fact that 90° is the largest viewing angle of practical interest, the Star markers are still the best, but their superiority is reduced substantially.

6. Color effects on off-axis detection were not simple. Given blinking markers such as the TCS Xenon devices, yellow seems to offer an advantage over red. For markers such as the blinking Star devices, red seems to offer an advantage over yellow.

7. Similarly, color and cycle (pulsed or steady) do not have simple effects with markers such as the Star lamps. Under the off-axis detection conditions of the test, blinking red markers were detected earlier than steady red markers. However, steady yellow markers were detected more readily than blinking yellow markers.

8. Subjective evaluations of visibility (ratings, rankings, and scaling of the markers) differentiated among the markers: Star and DSL markers were judged most visible of the lot tested.

9. The marker indicated by the field test data as being most readily detectible in both straight and curved approach conditions is the Star, yellow/steady incandescent marker.

10. If actual train operations will involve an observer first detecting a rear-end train marker with peripheral vision, it may be most effective to use a yellow marker such as the Star (for greater brightness than Star red provides), but include blink to provide attention-catching visual motion for an observer who may be distracted by other duties.

11. This field test was conducted under near ideal environmental and observer conditions. It is most properly considered a baseline comparison of a sample of rear-end train markers. Effectiveness of the markers under varying conditions of atmospheric transmissibility (fog, rain, snow), dirt buildup on the lens of the markers, obscurants on the cab windshield, clutter in the visual field, and/or high work load on the observer were not evaluated. These were considered to be outside the time and budget resources of this contract.

12. Under the conditions of the test, all markers are acceptable from the standpoint of the visual performance criteria mentioned above. This suggests other, non-visual, criteria be used for distinguishing among markers, if necessary. These criteria might include cost, reliability, availability, and maintainability. Alternatively, the results suggest that several different designs of rear-end train markers will be acceptable from a human factors standpoint.

Final Report

on

REAR-END TRAIN MARKER LIGHT EVALUATION
(Contract No. DTFR53-86-C-00006, Task Order No. 7)

1.0 INTRODUCTION

Beginning in January 1977, the Federal Railroad Administration (FRA) has required rear end marking devices mounted on the last car of all freight trains. The purpose of the regulation is to mark clearly the last car to provide a means for preventing rear-end collisions. The regulation is published in the Code of Federal Regulations (CFR), Part 221, "Rear End Marking Device - Passenger, Commuter and Freight Trains". The most applicable part of that regulation under paragraph 221.14, "Marking Devices", states, in part:

(a) "As prescribed in Section 221.13, passenger, commuter and freight trains shall be equipped with at least one marking device which has been approved by the Federal Railroad Administrator...and which has the following characteristics:

(1) An intensity of not less than 100 candela nor more than 1,000 candela (or an effective intensity of not less than 100 candela nor more than 1,000 candela for flashing lights) as measured at the center of the beam width;

(2) A horizontal beam with a minimum arc width of fifteen (15) degrees each side of the vertical center line, and a vertical beam with a minimum arc width of five (5) degrees each side of the horizontal center line as defined in terms of the 50 candela intensity points.

(3) A color defined by the red-orange-amber color range; and,

(4) If a flashing light is used, a flash rate of not less than once every 1.3 seconds or more than every 0.7 seconds."

Effective intensity is defined in part 221.5(h) as "...that intensity of a light in candela as defined by the Illuminating Engineering Society's Guide for Calculating the Effective Intensity of Flashing Signal Lights, November 1964."

To meet this standard, FRA approval of all rear-end marking devices is required. The requesting railroad must certify in writing, signed by the Chief Operating Officer, that among other things:

> "The device described in the submission (i.e., certification) has been tested in accordance with the current "Guidelines for Testing of FRA Rear End Marking Devices".

In Section 2.1.1 of the Guidelines, photometric tests are required to meet the intensity limits for an on-axis source candle power of between 100 and 1,000 candela (cd). For the off-axis (defined as ±15 degrees horizontally, ±5 degrees vertically), photometric tests must meet a source candle power between 50 and 1,000 cd. The output is determined with a suitable photometer. It should have an integrating mode to measure effective intensity of flashing or strobe lights.

The FRA allows both steady and flashing lights to be used. The intensity measurement for a steady light is a straightforward measurement of the peak intensity of the source (marker lamp) at a fixed distance (not less than 10 ft). For the flashing light, however, the intensity must be integrated across the flash period to compensate for the "apparent" brightness to the eye being less than its peak intensity. This sample integration is usually done with a calibrated filter in front of the photometer.

All rear end marker lights until very recently were incandescent bulbs of almost identical design. However, with the advent of the cabooseless train and battery-powered end-of-train devices, new technology using low-power LED and xenon flash tube lights were developed. Often these devices were designed to take advantage of the on-axis light intensity requirements. This could result in an asymmetrical light distribution of uncertainty in the spread of light beyond ±15 degrees horizontally, ±5 degrees vertically. This research project will help resolve these uncertainties with the new rear end marker light designs.

2.0 TEST OBJECTIVE

The objective of the tests under Task Order #7 was to evaluate a number of new rear end marker lights under both laboratory and field test conditions. Rear end marker lights of various designs, including incandescent, LED, and xenon flash tube, were obtained from four different manufacturers. Laboratory tests were then conducted to quantify the light performance. Procedures outlined in the "Guidelines for Testing of FRA Rear End Marking Devices" dated November 1977 were used as a basis for the laboratory tests. Photometric intensity, flash rate and color were measured for each device. Field tests were then conducted to assess the visibility to human observers of the sample of rear-end train marker designs.

3.0 LABORATORY MEASUREMENTS

Two types of measurements were made on the test lamps: relative spectral illuminance and angular luminous intensity. A list of the equipment used is given in Table 3-1, and a picture of the goniometer setup is shown in Figure 3-1. The test lamps are described in Table 3-2. For the three sets of lights requiring external power, 1 meter long 18 gauge stranded copper leads were used to minimize current-related (IR) voltage drops. The Pulse lamps were specified and run at 12.60 volts d.c. The DSL and STAR lamps were not specified and were run at 12.00 volts d.c.

The spectral measurements were relatively straightforward. The monochromator was set up to average over 3 or 4 pulses uniformly throughout the scan. The system was calibrated against the standard lamp to correct for any spectral bias. Chromaticity coordinates were computed by convolving the spectrum with the X, Y, Z tristimulus curves.

The angular intensity measurements were a bit more involved. Two sets of measurements, horizontal and vertical, were made for each light at distances of 25 feet and 100 feet. For horizontal measurements the lamp was placed upright on the goniometer. Data was taken from -18 to +18 degrees every 1 degree and thereafter to ±90 degrees every 5 degrees. For vertical

TABLE 3-1. EQUIPMENT USED IN LABORATORY EXPERIMENTS

	Manufacturer	Type	Model Number	Serial Number
Spectral Measurements:	EG&G	Intelligent Radiometer	GS4100	BS 329
	EG&G	Monochromator	NM3DM	GV 558
	EG&G	Photomultiplier Detector	D46CQ	PB9467
Luminance Measurements:	EG&G	Photomultiplier Detector Assembly	2020-10	273
	EG&G	High Efficiency Photometric Telescope	2020-31	120
Calibration Standard:	EG&G	Lamp Monitor and Control	RS3	MK1048
	EG&G	Spectral Radiance Head 49 fc ± 2.5% @ 25 cm 2851°K	RS10A	ML994
Test Lamp Power Supply:	Sorensen	1600 watt	SRL 60-17	189
Oscilloscope:	Tektronix		2430	B012349
Digital Multi-Meter:	Fluke	(.01%)	8840A	3758211

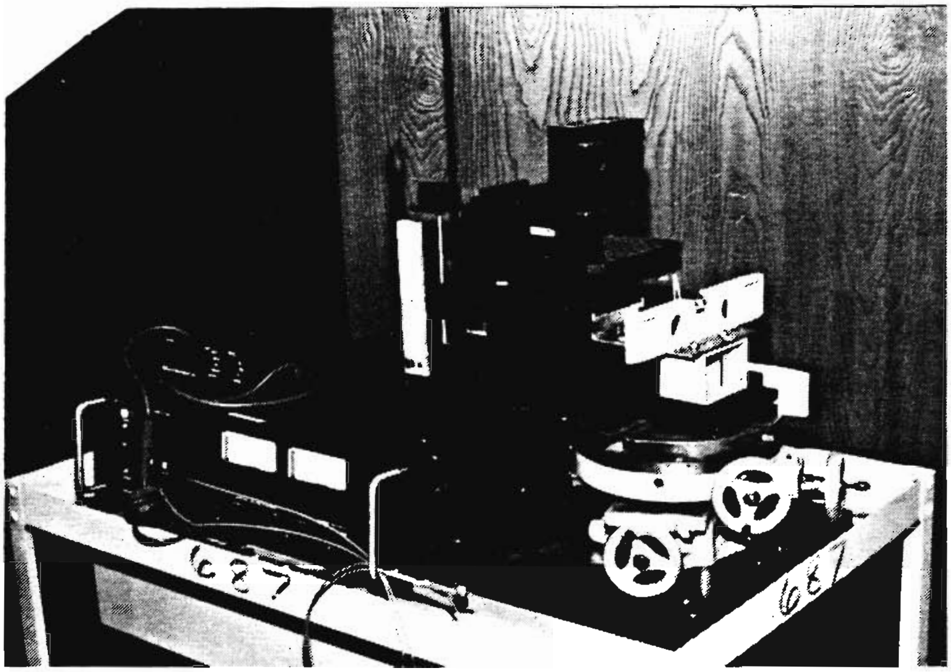

FIGURE 3-1. PHOTOGRAPH OF TEST SETUP

TABLE 3-2. DESCRIPTION OF REAR-END MARKER DEVICES

Manufacturer	Lamp Model	Serial Number	Lamp Type, Reflector Assembly
Dynamic Sciences Ltd.	HVM301-00F High Visibility Marker	2957, 2981, 2992	Xenon flash tube, non-diffused parabolic reflector, amber film on inside of glass cover.
Star Headlight & Lantern Co.	845 F Amber (2) 845 F Red (2)	Y1, Y2 R1, R2	#1156 Bulb, amber or red plastic Fresnel-type lenses.
Pulse Electronics, Inc	Trainlink HVM Light	203, 204, 205	Two perpendicular arrays of high-power red LED's, with a cylindrical Fresnel lens over each array. No filter.
Transit Control Systems	5390 End of Train Marker 84-1160-101 (2) 84-1160-102 (1)	 102, 104 103	Xenon flash tube with clear plastic diffuser over it, and red or amber plastic Fresnel lens over all.

measurements the lamp was placed on its side on the goniometer. The sense of the measurements, right, left, above, and below shows where the observer would be relative to the lamp normal. The goniometer has inherent precision of .05 degrees, but the lamps had to be mounted to it with equal precision. A combination of bubble levels and laser sightings with mirrors was used to ensure that:

(1) The telephotometer (TP) was level,
(2) The goniometer base was level on all axes,
(3) A line normal to the test lamp front surface was collinear with the TP line of sight.

Bubble levels were used for #1, and #2 as well as for setting the lamp on its side for "vertical" measurements. Laser sighting was used for #3 providing inherent precision of .0001 degree. However, a mirror was used on the lamp itself for this part, and positioning the mirror was rather difficult for some lamps. From the pictures of the lamps given in Figures 3-2 through 3-5, it can be seen that not one is similar another and none had a standard mount or method of attachment. Some had no obvious attachment fixture at all and most had no true flat surface which could be used as a reference for positioning. However, a method was developed for each type and maintained at both 25 feet and 100 feet:

DSL lamps:	Front glass window used as reference surface.
Pulse lamps:	Cylindical Fresnel lens used as reference.
STAR lamps:	Back of lamp used as reference, lines scribed on back with a square for vertical positioning.
TCS lamps:	Shroud over lense used as reference with a flat steel plate.

The actual intensity measurements were indirect. The standard lamp, calibrated in terms of illuminance at a given distance, was used to generate a calibration constant for the telephotometer (TP). At a certain high voltage, with the standard lamp completely inside the TP field of view, a constant was obtained relating the TP anode current-related voltage (IR) drop across a

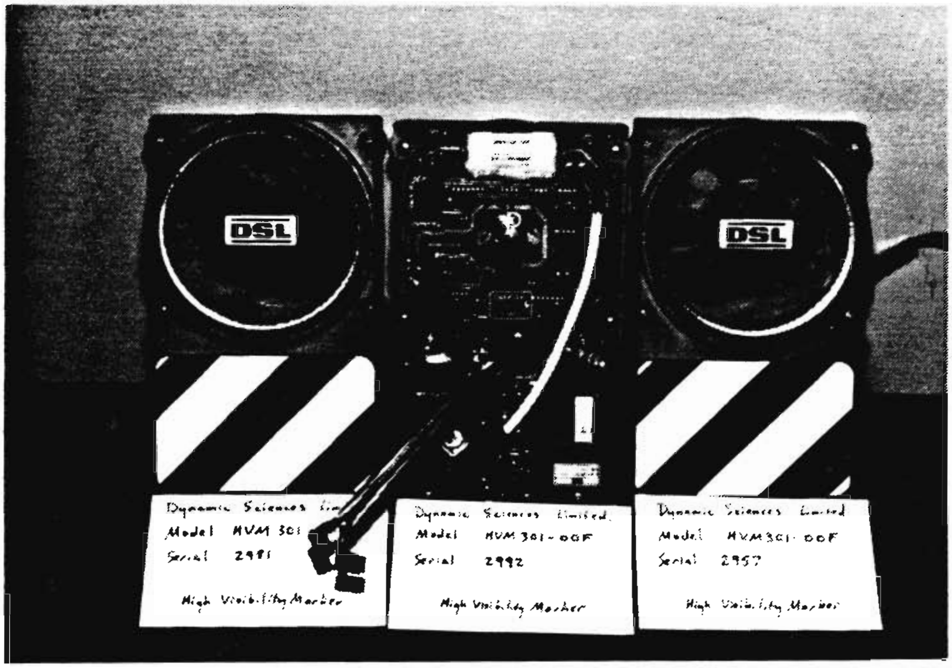

FIGURE 3-2. DYNAMIC SCIENCES LIMITED

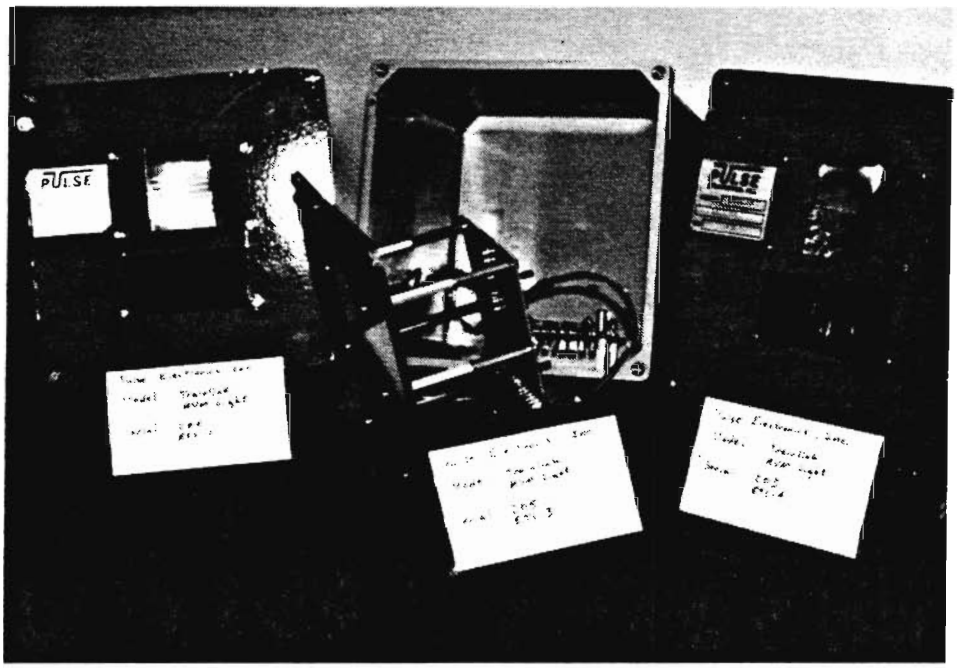

FIGURE 3-3. PULSE ELECTRONICS, INC.

FIGURE 3-4. STAR HEADLIGHT AND LANTERN COMPANY

FIGURE 3-5. TRANSIT CONTROL SYSTEMS

known impedance to the illuminance at the TP entrance pupil. The illuminance from the standard lamp, at a distance r is given by:

$$E = E_s (d/r)^2 \qquad (3\text{-}1)$$

where E_s is the calibrated source illuminance, and d is the distance at which E is specified. The illuminance of the test lamps at a known distance was the actual quantity measured. The luminous intensity was inferred from the following relations. Illuminance is defined by:

$$E = \text{lm/area} \qquad (3\text{-}2)$$

where lm are the lumens passing through the area. In this case, the area is just the area of the TP entrance pupil (its limiting aperture).

$$E = \text{lm/(pupil area)} \qquad (3\text{-}3)$$

The desired quantity, luminous intensity, I (candlepower) is given by:

$$I = \text{lm/sr}, \qquad (3\text{-}4)$$

where lm are the lumens contained in the solid angle sr, defined by sr = (measurement area)/(distance to measured area)^2. Here the measurement area is the area defined by the TP entrance pupil and the distance is the distance from the test lamp to the TP entrance pupil, so that:

$$I = \text{lm/sr} = \text{lm/(pupil area)/(distance-to-pupil)}^2$$

$$= \text{lm (distance)}^2\text{/(pupil area)} = E\ \text{(distance)}^2 \qquad (3\text{-}5)$$

For example, a calibration constant was obtained for one set of conditions. The calibration source illuminance was measured at 17 feet 2 inches (523 cm). The signal level = 820 μV, with a neutral density filter = 1.88. The actual illuminance was calculated from the calibration value of 49 foot-candles (fc) at 25 cm. The square of the ratio of the measurement distance to the calibration distance is $(523/25)^2 = 438$, so that:

E at 17 feet 2 inches = 49/438 = 0.112 fc

Then the calibration constant for this set of conditions equals:

$(0.820 \text{ mV})(10^{1.88})/0.112 \text{ fc} = 555 \text{ mV/fc}$.

Then the DSL #2957 lamp measured on axis, horizontal, at 26 feet with a neutral density filter = 4 and with 106 mV output would be:

(measured output)(filter coefficient)(distance)/(cal. constant)

$= (106 \text{ mV})(10^4)(26 \text{ ft})^2 /(555 \text{ mV/fc}) = 1.29(10)^6$ candela.

4.0 LABORATORY RESULTS

4.1 Test Data

There are two major sections of data: spectral data and intensity data. The spectral data include the lamp spectrum taken from 380-780 millimicrons (nanometers) and normalized to its maximum value. The chromaticity coordinates are summarized in Table 4-1. Plots on linear and log scales are included in Appendix A for each lamp.

The intensity data have two sections, one for 25-foot data and the other for 100-foot data. All measurements were made from the peak of the waveform on a high-speed oscilloscope. Sample waveforms are shown in Figures 4-1 through 4-4. A summary of lamp pulse widths, periods, and duty cycles is given in Table 4-2. Once again, linear and logarithmic plots are given for each lamp/orientation in Appendix B for 25-ft measurements, and in Appendix C for 100-ft measurements. There are four additional plots for the Pulse lamp

TABLE 4-1. SUMMARY OF 1931 AND 1976 CIE CHROMATICITY COORDINATES

Lamp	1931 x	1931 y	1976 u'	1976 v'
DSL				
2957	.635	.365	.416	.538
2981	.648	.352	.437	.534
2992	.628	.371	.405	.539
PULSE				
203	.720	.279	.587	.512
204	.727	.273	.604	.509
205	.720	.280	.585	.512
STAR				
R1	.679	.321	.495	.526
R2	.679	.321	.494	.526
R2S	.677	.320	.494	.525
Y1	.589	.411	.349	.548
Y2	.587	.413	.346	.548
Y2S	.588	.406	.352	.546
TCS				
102	.692	.308	.522	.522
103	.581	.419	.388	.549
104	.667	.333	.470	.529

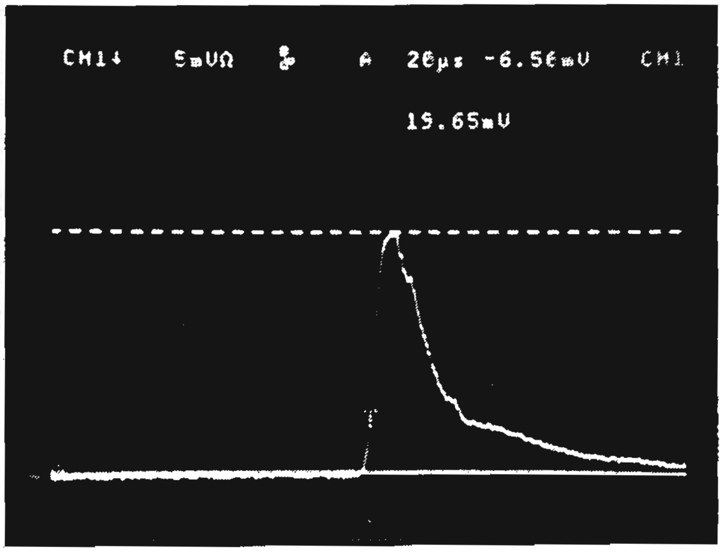

FIGURE 4-1. DSL LAMP #2957 AT 0 DEGREES

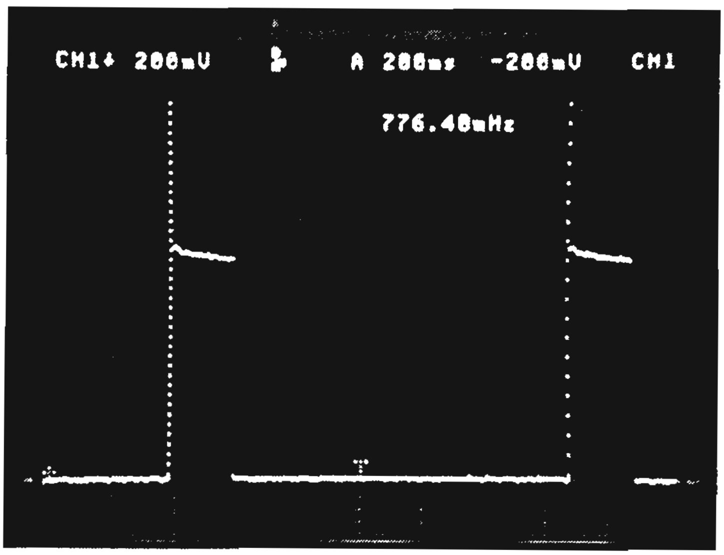

FIGURE 4-2. PULSE LAMP #205 AT 0 DEGREES

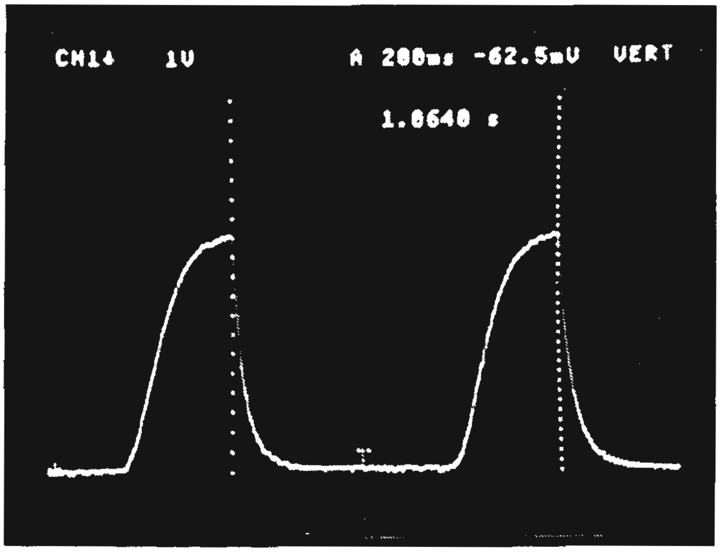

FIGURE 4-3. STAR LAMP Y2 AT 0 DEGREES

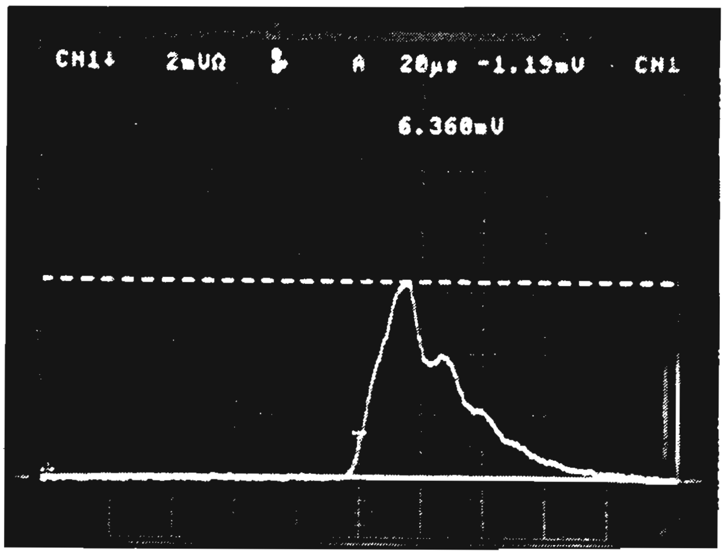

FIGURE 4-4. TCS LAMP #102 AT 0 DEGREES

TABLE 4-2. SUMMARY OF LAMP DUTY CYCLES

Lamp	Pulse Width	Pulse Period	Width/Period
DSL			
2957	18 μs	1.150 sec	$1.56 \cdot 10^{-5}$
2981	16 μs	1.150	$1.39 \cdot 10^{-5}$
2992	17 μs	1.145	$1.48 \cdot 10^{-5}$
PULSE			
203	305 ms	1.159	0.263
204	205 ms	1.153	0.178
205	205 ms	1.158	0.177
STAR			
R1	260 ms	1.040	0.250
R2	250 ms	1.004	0.249
Y1	245 ms	1.036	0.236
Y2	260 ms	1.064	0.244
TCS			
102	26 μs	1.080	$2.41 \cdot 10^{-5}$
103	24 μs	1.060	$2.26 \cdot 10^{-5}$
104	26 μs	1.020	$2.55 \cdot 10^{-5}$

#203, two for 25 feet, the others for 100 feet. They show the intensity profile through the cross pattern for both legs at varying off-axis locations. This was not done for the other lamps because they are spherically symmetric. The sketch in Figure 4-5 shows where the measurements were made.

Peak and effective intensities are given in Tables 4-3 through 4-6 for the different manufacturers' rear-end marker samples. For the xenon flashlamp type samples (DSL and TCS), Formula 3-28 of the 1978 IES Lighting Handbook (Formula 2-22 of the 1966 version) was used. For the longer pulse-duration lamps, Formula 3-27 (2-21 for 1966) was used. Both formulas involve integra-ting the pulse to obtain pulse energy. Since the pulse shapes for lamps of identical design were similar, only one representative photograph for the pulse shape for each lamp was reported, Figures 4-1 through 4-4. Absolute differences in pulse duration are shown in Table 4-2. A planimeter was used to integrate the pulse for each lamp type. That lamp constant was then scaled by the peak height, obtained from the 100-ft intensity distribution data, and the given pulse duration from Table 4-2.

4.2 Observations

Although measurements were proposed at 10 feet and 100 feet, early data on the Pulse lamps (they were received first) showed that the $1/R^2$ relation did not hold true. The 10 feet data were too high when compared with the 100 feet data. Presuming that the presence of the cylindrical lens in front of the diodes was disrupting the point source approximation at 10 feet, subsequent measurements were made at 25 feet nominally.

The quantity luminous intensity should be constant for any lamp at any distance, assuming the lamp resembles a point source. Comparing the 25 and 100 feet data for each lamp shows that maximum peak intensities differ non-systematically by approximately 15 percent. Significant sources for this error are as follows:

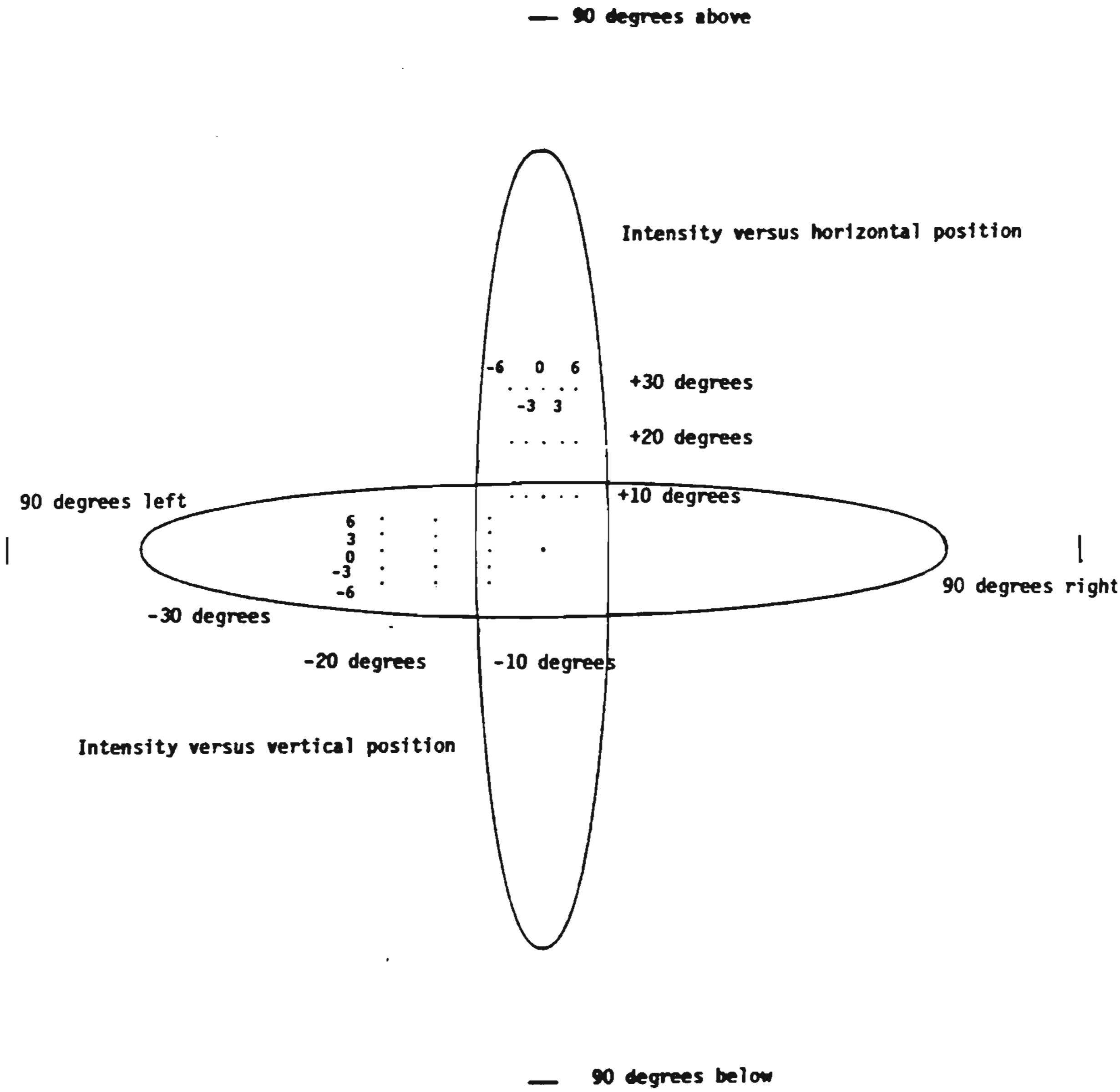

FIGURE 4-5. IDEALIZED INTENSITY PROFILE OF PULSE LAMP #203 FROM OBSERVER'S VIEW SHOWING EXTRA MEASUREMENTS

TABLE 4-3. INTENSITY VALUES FOR DSL REAR-END MARKERS

Lamp Orientation	Value	Tested Device Number #1	#2	#3	49CFR 121 Specification Limit Value Minimum	Maximum
H-V	Peak[a]	$1.3(10)^6$	$.94(10)^6$	$1.6(10)^6$	100	1,000
	Eff.[b]	180	116	203		
H-15°R	Peak	$.29(10)^6$	$.27(10)^6$	$.33(10)^6$	50	1,000
	Eff.	40	33	43		
H-15°	Peak	$.25(10)^6$	$.24(10)^6$	$.29(10)^6$	50	1,000
	Eff.	35	30	38		
V-5°U	Peak	$.25(10)^6$	$.30(10)^6$	$.28(10)^6$	50	1,000
	Eff.	35	37	37		
V-5°D	Peak	$.23(10)^6$	$.24(10)^6$	$.27(10)^6$	50	1,000
	Eff.	32	30	35		

Note: H-V is defined as the geometrical horizontal/vertical center.

a -- Peak intensity in candela;

b -- effective intensity in candela-seconds.

TABLE 4-4. INTENSITY VALUES FOR PULSE REAR-END MARKERS

Lamp Orientation	Value	Tested Device Number #1	#2	#3	49CFR 121 Specification Limit Value Minimum	Maximum
H-V	Peak[a]	112	107	130	100	1,000
	Eff.[b]	46	55	67		
H-15°R	Peak	49	64	27	50	1,000
	Eff.	20	33	14		
H-15°	Peak	45	53	30	50	1,000
	Eff.	19	27	15		
V-5°U	Peak	52	49	66	50	1,000
	Eff.	22	25	34		
V-5°D	Peak	48	41	60	50	1,000
	Eff.	20	21	32		

Note: H-V is defined as the geometrical horizontal/vertical center.

a -- Peak intensity in candela;

b -- effective intensity in candela-seconds.

TABLE 4-5. INTENSITY VALUES FOR STAR REAR-END MARKERS

Lamp Orientation	Value	Tested Device Number #1	#2	#3	49CFR 121 Specification Limit Value Minimum	Maximum
		RED LENSE				
H-V	Peak[a]	142	153		100	1,000
	Eff.[b]	70	72			
H-15°R	Peak	55	50		50	1,000
	Eff.	27	24			
H-15°	Peak	50	47		50	1,000
	Eff.	25	22			
V-5°U	Peak	82	82		50	1,000
	Eff.	40	39			
V-5°D	Peak	80	80		50	1,000
	Eff.	39	38			
		AMBER LENSE				
H-V	Peak[a]	475	315		100	1,000
	Eff.[b]	219	154			
H-15°R	Peak	175	170		50	1,000
	Eff.	81	83			
H-15°	Peak	160	140		50	1,000
	Eff.	74	69			
V-5°U	Peak	230	205		50	1,000
	Eff.	106	100			
V-5°D	Peak	240	170		50	1,000
	Eff.	111	100			

Note: H-V is defined as the geometrical horizontal/vertical center.
a -- Peak intensity in candela;
b -- effective intensity in candela-seconds.

TABLE 4-6. INTENSITY VALUES FOR TCS REAR-END MARKERS

Lamp Orientation	Value	Tested Device Number #1[c]	#2[d]	#3[c]	49CFR 121 Specification Limit Value Minimum	Maximum
H-V	Peak[a]	1910	7400	1850	100	1,000
	Eff.[b]	.27	.98	.27		
H-15°R	Peak	1800	6500	1750	50	1,000
	Eff.	.26	.86	.25		
H-15°	Peak	1950	7200	1980	50	1,000
	Eff.	.28	.95	.28		
V-5°U	Peak	2040	6600	1950	50	1,000
	Eff.	.29	.87	.28		
V-5°D	Peak	1910	6600	1950	50	1,000
	Eff.	.27	.86	.25		

Note: H-V is defined as the geometrical horizontal/vertical center.

a -- Peak intensity in candela;

b -- effective intensity in candela-seconds.

c -- red lens

d -- amber lens

Electronic

(1) Random noise associated with photomultiplier used in TP.

(2) Fluctuations in test lamp electronics, changing lamp output.

Optical

(1) Uncertainty in precise value of neutral density filters used to keep TP out of saturation (filters are wavelength dependent).

Of these sources, the test lamp fluctuations could be observed directly. Pulses were observed in real time on the oscilloscope and a cursor was set by hand on the peak. Both DSL and TCS, and to a lesser extent Pulse, showed variations in peak heights. The xenon flash tube lamps appeared cyclical with a very strong peak being followed by a very weak one, then increasing to an intermediate peak. The difference between strong and weak was as high as 20 percent.

The values of neutral density were determined individually for each lamp type to compensate for wavelength dependence. The error involved was ≤5 percent when using the standard lamp (white light), but light output fluctuations already mentioned complicated determining the filter value for the xenon lamps. Repeated measurements were made to generate average values for peak intensity, enabling filter values to be determined to ≤10 percent.

The data show positioning accuracy and repeatability was excellent. Intensity profiles for 25 feet match very closely those for 100 feet, with one exception. The vertical measurement for Pulse #204 appears to have been misaligned by several degrees. The profile is correct but the absolute position is off.

4.3 Comparison with ETL Test Results

As part of their FRA qualification, the manufacturers had an independent commercial laboratory -- ETL Testing Laboratories, Inc., of Cortland, NY -- test five of each device. In comparing the ETL intensity measurements with Battelle's results, the FRA found that ETL's intensity numbers, both peak (where given) and effective, were consistently higher. This is shown in Table 4-7. The FRA, ETL and Battelle joined in an effort to resolve these discrepancies.

The following significant differences were established between Battelle's and ETL's test methodologies:

(1) Different methods of mounting the devices were used. They were, in most cases, delivered both to Battelle and ETL without proper mounting surfaces. Battelle established practical reference planes for each, using the nominal geometric center and maintaining this for both 25-ft and 100-ft measurements. ETL searched for the "hot spot" (point of highest intensity), which does not necessarily coincide with the geometric center.

(2) Battelle used different voltage excitations than ETL used for several of the devices. When the voltage was not specified, Battelle used 12.0 volts from a regulated power supply. ETL may have used up to 0.8 volt higher excitation. From previous measurements of locomotive headlight intensities at 30 and 22 volts, the intensity varied as the 4^{th} power of the voltage ratio.

(3) Some of the tested units were different serial numbers, even different model numbers (although these were said to be the same basic units). Some of the units were delivered to Battelle with different candlepower bulbs from the ETL units.

(4) It was noted that, particularly with the flash tube devices, a rather large variance in pulse peak intensity (from pulse to pulse) was observed. This variance was given as ± 10 percent for the DSL lamp.

Other aspects of the measurements -- the shape and duration of scope-recorded pulses, and the chromaticity coordinates -- checked closely from one laboratory to the other.

In order to determine the cause of the different intensity values, Battelle staff traveled to the ETL laboratory to compare standard sources and to measure three of the rear-end marker devices with both sets of equipment.

TABLE 4-7. COMPARISON OF REAR-END MARKER LIGHT INTENSITY TEST RESULTS

Mfg.	Type of Device	Pulse Width	Tested Units BCD	Tested Units ETL	Ave. Peak I (cd) Battelle	Ave. Peak I (cd) ETL	Ave. Eff. I (cd-s) Battelle	Ave. Eff. I (cd-s) ETL
DSL	Xenon flash tube	17 μs	3	5	$1.3(10)^6$	na	166	291
Star	Incandescent lamp, red	255 msec	2	5	148	525 cw	71	248
	, amber	253 msec	2	5	395	na	187	538
Pulse	LED array	238 msec	3	5	116	na	56	128
TCS	Xenon flash tube, red	25 μs	2	5	1880	3120	0.27	na
	, amber	25 μs	1	5	7400	10100	0.98	na

Note: Effective intensity is calculated by integrating over the pulse and using the appropriate IES formula.

The standard sources were compared first. Battelle's telephotometer was calibrated first with its source, and then with ETL's source. Our reading was 1.9 percent high relative to the ETL calibration data. Next, the Battelle equipment, which had been calibrated at 25 feet, was moved to 50 and 100 feet. At each location the reading was 11 percent low. This discrepancy remained constant regardless of the source. We concluded that the reticle eyepiece image plane on the telephotometer was not confocal with the field stop image plane. This caused the image at the field stop to be out of focus and the intensity reading to be low. Our original data did not exhibit this problem, but the equipment had been heavily used since these measurements were made and must since have become misaligned. Since the error was relatively small, the comparative testing was continued.

The three rear-end marker devices were then measured at 100 ft with the same equipment used previously. Since the calibration was done at 25 ft, the results were expected to be 11 percent lower than ETL's. ETL's system for mounting and pointing the devices was used, and the measurements were made very close to the location used by ETL. Results of these measurements are summarized in Table 4-8 and compared with subsequent measurements on the three devices made by ETL with their equipment. With the exception of the Star lamp, the results are quite similar. ETL noted that in testing the Star lamp, the mounting was loose, and a slight shift could result in different measured values.

Based on these comparative tests, it appears that the differences in mounting techniques account for the major differences in measured intensity. The recommended approach to avoid these differences is to require the device manufacturer or applicant to supply a mounting base or test stand to insure proper alignment during testing. Since devices are also occasionally submitted in prototype form, tests should be required on production-run devices to assure compliance with FRA requirements.

TABLE 4-8. COMPARISON OF LIGHT INTENSITY MEASUREMENTS UNDER SIMILAR TEST CONDITIONS

Device	Differences from Previous Tests	Peak I (cd)	Effective I (cd-s) Battelle	Effective I (cd-s) ETL	Previous Data
DSL #2957	Same unit as tested (Device #1)	$1.23(10)^6$	234	252	180
STAR #1089	Different bezel and reflector	304	164	224	187
TCS #156	Different unit	$1.12(10)^4$	1.11	0.97	0.98

Note: Effective intensity is calculated by integrating over the pulse and using the appropriate IES formula.

5.0 FIELD EXPERIMENTS

As a second phase to this program, a field test was conducted to assess the visibility of the sample rear-end train markers. Experiments were designed to test the conspicuity of markers differing in lamp type, color, light cycle (pulse versus steady), and luminance. A fundamental issue is whether human observers (i.e., locomotive engineers) can adequately detect the markers when approaching the end of another train on either tangent or curved track.

Tangent-track approaches involve on-axis viewing of a marker. On the other hand, curved-track approaches involve off-axis viewing of a marker, the degree of which depends on how curved the track is and the location of the human observer relative to the marker light at any point in time. The FRA has suggested that, to insure safety under conditions of a slow approach at 15 mph, a human observer should be able to see a rear-end train marker light such that at least one thousand feet (1000') of track stopping distance remains when detection occurs.

The objective of this field test was to assess the visibility to human observers of a sample of rear-end train marker designs. A variation of best-case/worst-case analysis was employed in the field test. The testing involved an on-axis viewing condition which represents the "best case" for lights designed to take advantage of on-axis light intensity requirements. The off-axis viewing condition, simulating an approach on a curved track, represents the "worst case" for lights designed primarily to emphasize on-axis light intensity. This field test used both subjective assessments and visual detection performance to assess a sample of eight different rear-end train marker lights provided to Battelle by the manufacturers. The eight samples were chosen from the markers in the previous photometric evaluations: one device for each manufacturer (two, if both amber and red lenses were submitted), plus pulsed and steady-light conditions for the Star lamps.

5.1 Experimental Background

The Federal Railroad Administration (FRA) has indicated that rear-end markers should be detectible such that, assuming a slow approach at 15 mph, there is at least 1000' of track stopping distance available to the locomotive engineer upon detecting the marker of another parked or slow-moving train. This 1000' circular (stopping) distance implies that markers should be detectible at a viewing angle, θ, of 1 radian (57.3°) or more. (See Appendix D for further explanation.) The implication of this result is that any rear-end marker which is visible at an angle of 57.3° or greater is acceptable from the standpoint of human visual performance. In such a case, other criteria such as cost, maintainability, reliability, etc., could be used to choose from among several products. Alternatively, the implication is that several products are satisfactory from the standpoint of human visual performance.

The geometry of the curved track approach suggested an alternative methodology which would obviate the need to use a curved track for data collection. The logic of this alternative methodology is given below. As indicated in Figure 5-1, as an observer travels around a curve and approaches a train marker, the angle θ between the marker's emitter line and the observer's line of sight grows smaller and this 'exposes' more of the marker to the observer. The angle θ, then, determines the marker's detection. This angle can also be directly related to stopping distances. Given these results, instead of testing with a stationary marker and a moving observer, it was possible to conduct a simulation with a stationary observer and a moving marker. Specifically, an observer was situated at a fixed distance of 1000' from a marker seated on a turntable. A trial started with an angle of more than 90° between the marker's emitter line and the observer's line of sight so the observer could not see the marker at the outset (hence the term "off-axis" viewing condition). The marker was then rotated slowly toward the observer until the observer signaled that he/she detected the marker. The detection angle was recorded as the dependent variable for each of the markers and used to assess the effects of various markers on the ability of human observers to see them. By virtue of the simulation just described, if a marker was detected by, say, rotating a marker (with respect to a stationary observer) to

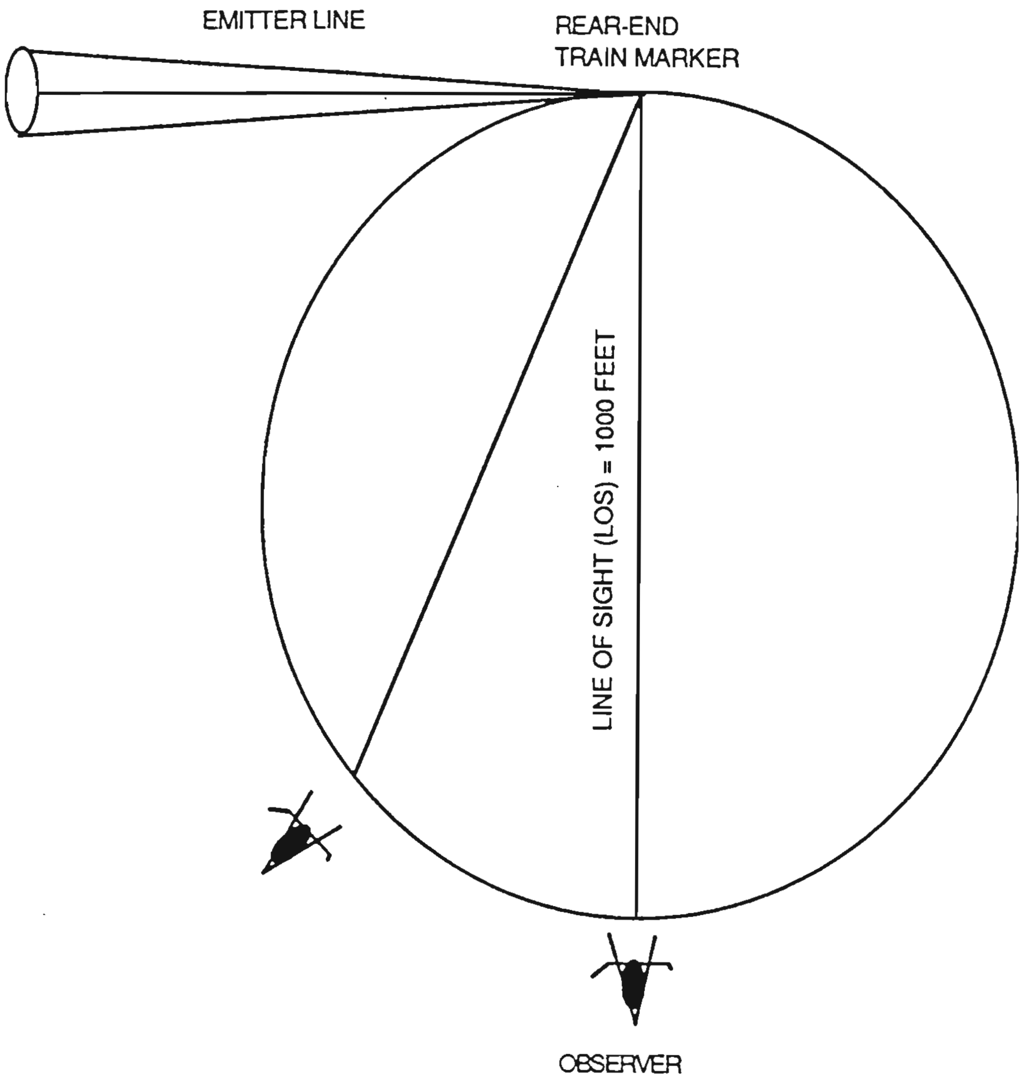

FIGURE 5-1. GEOMETRY OF A CURVED-TRACK APPROACH TOWARD A REAR-END MARKER DEVICE

a detection angle of 85^{o}, this is analogous to a moving observer detecting a stationary marker by moving through an angle of $90^{o} - 85^{o} = 5^{o}$ from the starting point on the opposite side of a circular track. Thus, visual performance data were collected to evaluate the visibility of the sample of rear-end train markers. Appendix D contains further explanation of the geometry of curved track approaches.

Consider next a slow approach along a tangent track. Previous research for the FRA on rear-end train markers (Sherman, Ray, and Meacham, 1984), informal observations made by the investigators, and data from a small pilot study conducted for this effort all indicated that a detection task was not feasible because all of the markers were clearly visible at a distance of 1000' in the on-axis viewing condition. As an alternative, subjective assessments of marker visibility were collected using both rating scales and pair comparisons. Details of the approach used and results collected are presented below.

5.2 Human Subjects for Experiments

The subjects in the field test included 14 male and 10 female volunteers of ages 24 to 57 years. All subjects were screened by Battelle Health Services to insure Snellen acuity of 20/30 or better (corrective lenses were allowed) as measured by a Titmus testing device. Subjects were also screened to insure that subjects exhibited no color vision problems as assessed by means of the Ishihara color plates. By direction of the FRA technical representative, no railroad personnel or people with railroad experience were included in the subject pool. This was done to eliminate any biases regarding preferences of markers due to prior exposure to similar types of markers. Subjects were paid $25.00 for their participation in the field test and signed a subject consent form as required by Battelle policy. Table 5-1 shows the distribution of the subject sample by age and gender.

TABLE 5-1. DISTRIBUTION OF SUBJECTS IN THE FRA REAR-END TRAIN MARKER FIELD TEST BY AGE AND GENDER

Age	Gender		Row Totals
	Male	Female	
24 - 29	2	2	4
30 - 39	2	5	7
40 - 49	6	2	8
50 - 59	4	1	5
Column Totals:	14	10	24

5.3 Experimental Apparatus

5.3.1 Equipment

Eight train markers were evaluated in this study. The markers possessed the following characteristics:

TABLE 5-2. DESCRIPTION OF REAR-END MARKER TYPES AND CONDITIONS

No.	Manufacturer	Description	Color	Cycle
1.	Star Headlight and Lantern	Incandescent	Red	Pulsed
2.	Star Headlight and Lantern	Incandescent	Red	Steady
3.	Star Headlight and Lantern	Incandescent	Yellow	Pulsed
4.	Star Headlight and Lantern	Incandescent	Yellow	Steady
5.	Pulse Electronics, Inc.	LED	Red	Pulsed
6.	Transit Control System	Xenon Pulse	Red	Pulsed
7.	Transit Control System	Xenon Pulse	Yellow	Pulsed
8.	Dynamic Sciences, Ltd.	Xenon Pulse	Red	Pulsed

The markers were mounted on acrylic bases to provide stable supports and help in positioning. For the detection task, they were placed on a circular plywood turntable which was painted black to reduce the amount of reflected light. Holes drilled in the turntable provided standardization of positioning of the markers on the turntable. A 1.8 hp motor, mounted on a stand beneath the turntable provided a fixed rate of rotation (1.25 deg/sec, as shown in the derivation of Appendix D, page D-4).

Three battery-powered button switches, located at the observer site, were activated by the subjects upon detection of the marker. These switches were connected, via a length of 1000' multi-channel cable, to three electronic counter timers (Fluke Model 1950A) which recorded the times when the subjects depressed their switches. A dual-regulated power supply connected to both the motor and all three of the counters provided the means of simultaneously starting the turntable rotation and activating the counters. A button press by a subject stopped the appropriate counter; the numeric value displayed on that counter represented detection time in seconds, i.e., the time that elapsed between the start of turntable rotation to detection of the marker by that subject. Since the degree of turntable rotation was constant, the detection angle was easily calculated from the detection time and a known starting position. An extension cord, connected to an outlet in a nearby guard house at Battelle's West Jefferson, Ohio, test site, provided the necessary AC power for the power supply and the electronic counters. The equipment at the marker site was set up on top of a 38" high folding table which was placed in the center of the road used for testing, thus ensuring fairly consistent positioning of equipment throughout the eight days of testing.

A 12-volt marine battery, enclosed in a carrying case for ease of handling, provided the power source for six of the eight markers. The other two markers, (Transit Control System lights) had self-contained power sources. See Figures 5-2 through 5-6 for schematic diagrams and photographs of the experimental set-up, test site, and arrangement of subjects during testing.

Hand-held two-way radios provided the means of communicating between the observer and marker sites, separated by 1000'. In some instances, signaling by flashlights was sufficient to indicate the start or end of a trial.

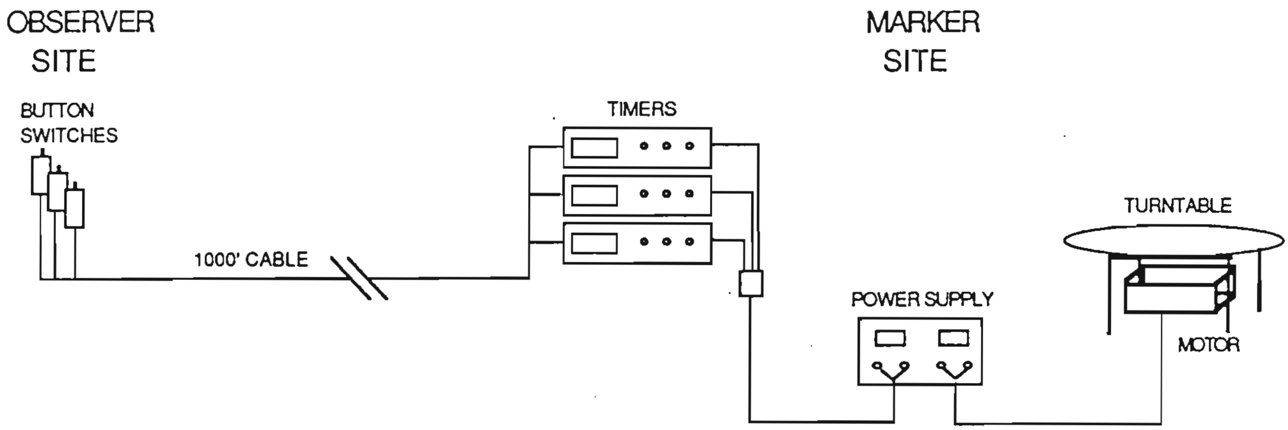

FIGURE 5-2. SCHEMATIC DIAGRAM OF EQUIPMENT FOR FIELD TESTS

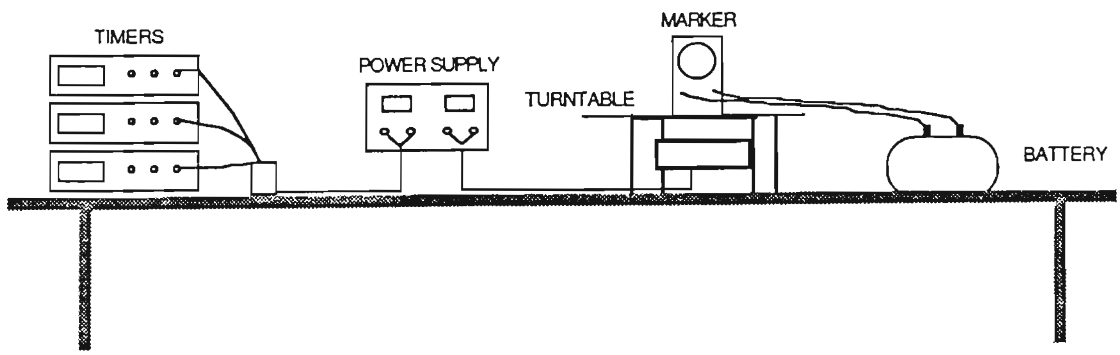

FIGURE 5-3. ARRANGMENT OF EQUIPMENT AT MARKER SITE

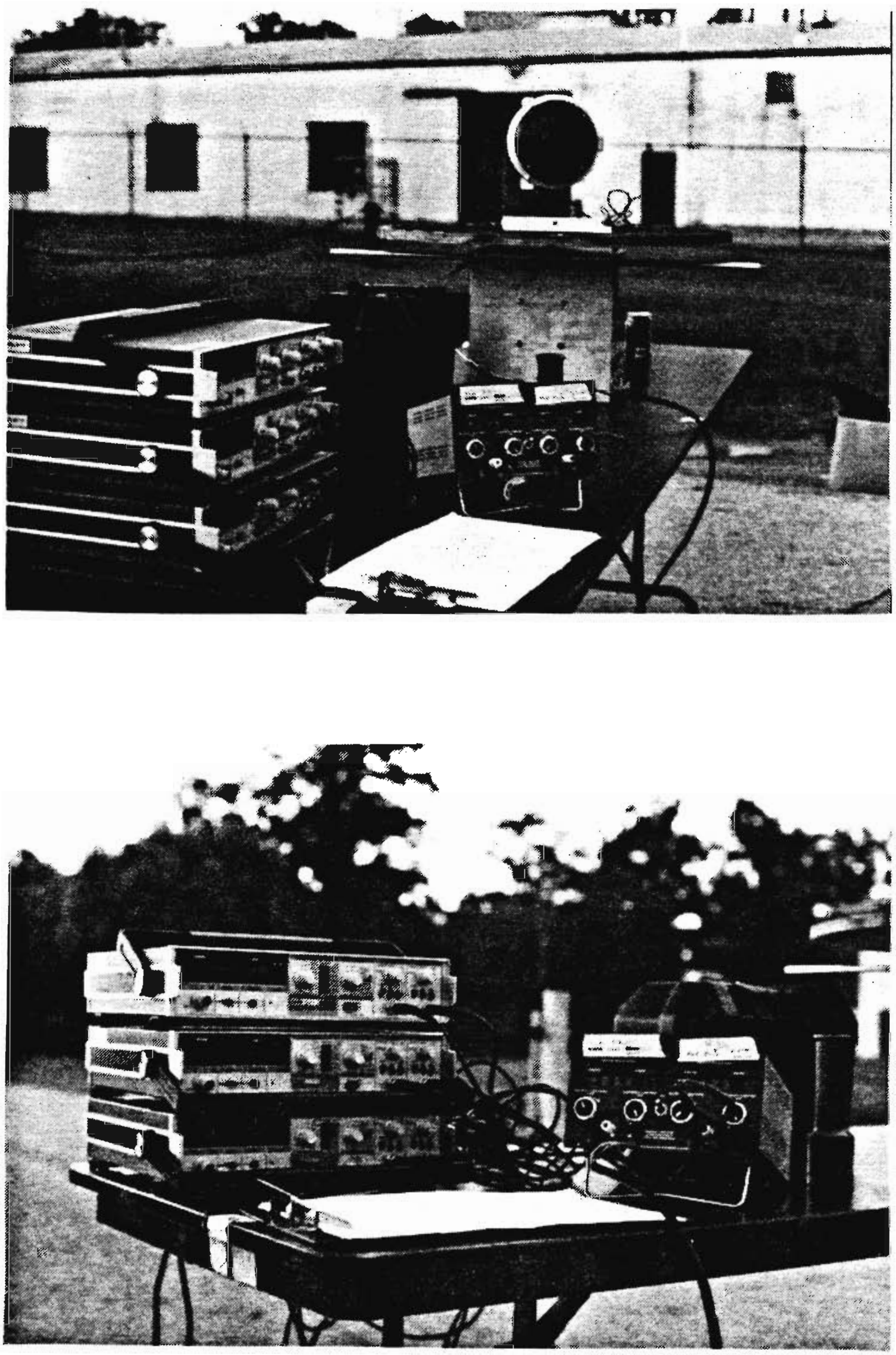

FIGURE 5-4. PHOTOGRAPHS OF EQUIPMENT SET UP AT MARKER SITE

FIGURE 5-5. POSITION OF SUBJECTS DURING TESTING

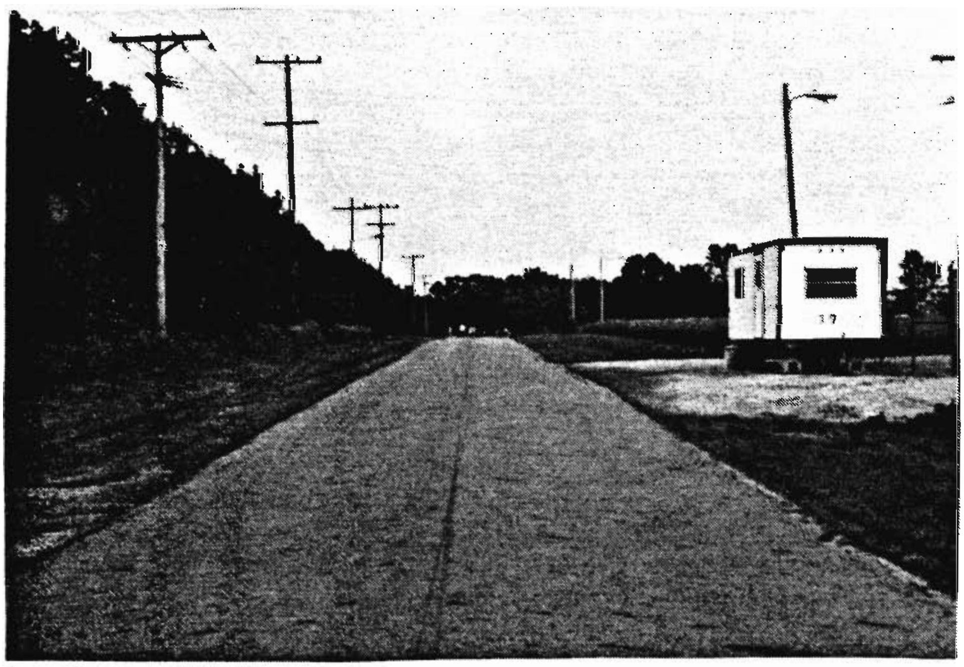

FIGURE 5-6. EXPERIMENTAL TEST SITE, LOOKING FROM OBSERVER SITE TOWARD REAR-END MARKER SITE, 1000-FT AWAY

5.3.2 Experimental Design

In order to minimize systematic learning and fatigue effects, the subjects were given trials scheduled according to the following Latin-square:

	SUBJECT NUMBER	Sequence of 4-Trial Blocks 1	2	3	4	5	6	7	8
Session 1	01, 02, 03	A	B	C	D	E	F	G	H
2	04, 05, 06	B	C	D	E	F	G	H	A
3	07, 08, 09	C	D	E	F	G	H	A	B
4	10, 11, 12	D	E	F	G	H	A	B	C
5	13, 14, 15	E	F	G	H	A	B	C	D
6	16, 17, 18	F	G	H	A	B	C	D	E
7	19, 20, 21	G	H	A	B	C	D	E	F
8	22, 23, 24	H	A	B	C	D	E	F	G

The codes for the markers are as follows:

A Star/Yellow/Pulsed
B Pulse/Red/Pulsed
C TCS/Yellow/Pulsed
D Star/Red/Pulsed
E Star/Yellow/Steady
F TCS/Red/Pulsed
G DSL/Red/Pulsed
H Star/Red/Steady.

5.4 Experimental Procedure

Testing was conducted at Battelle's facilities in West Jefferson, Ohio, located approximately 20 miles west of Columbus. The test site was a straight, flat section of road, selected so as to ensure that a clear line of sight of 1000' was available, i.e., with no obstructions such as buildings, trees or bushes. An additional requirement was that the test site was dark, with no nearby lights which would distract or confuse the subjects. Thus, nearby security lights were extinguished for the duration of the experiment. The site where the markers were placed was selected to avoid any nearby objects which might reflect light from the markers, thus providing secondary cues as to the markers' position. When necessary, dark cloth was draped over reflective posts and signs in the vicinity of the markers to eliminate unwanted reflections.

The experimental sessions were scheduled on nights with no precipitation; skies varied from clear to cloudy. The sessions lasted between the approximate hours of 9:30 and 11:30 p.m. It was felt that variability introduced by the nighttime skies was not a significant factor in the experiment. Also, there was nothing that could be done to control this factor. Subjects were given directions and maps to the test location, and were informed of their assigned test session. Three subjects were scheduled per test session. Upon arrival at the test location, they were greeted by the experimenter, given a brief overview of the experimental procedure, and shown the marker lights and equipment set up at the marker site. The subjects then entered a mini-van and were driven to the observation site, located 1000 feet away from the marker location; the mini-van was then parked and served as the observation site. Once at the observation site, the subjects were given a more detailed description of the experiment. The experiment was conducted in three phases:

Phase I: Visibility and Glare Rating. The subjects were given clipboards containing the data sheets with rating scales for marker visibility and glare. After they were given instructions on this phase of the experiment, the first marker was turned on. The marker was located at the marker site and positioned so that it directly faced the subjects (the on-axis viewing condition). The marker remained on for 15-20 seconds and was then turned off. During this time, the subjects looked at the marker, evaluated it with respect to its visibility and glare, then indicated their choices on the visibility and glare scales on the data sheet. After the first marker was finished, it was replaced by the next marker, and the process was repeated until all eight markers had been evaluated.

Phase II: Detection Task. In this phase of the experiment, the first marker was placed on a turntable, with the face of the marker turned 120 or 180 deg away from the subjects (0 deg represented the position in which the marker was directly facing the subjects); starting positions were determined for each marker from a pilot study. A schematic diagram of the marker starting position relative to the subjects is given in Figure 5-7. The marker was turned on and the motor activated, causing the marker to rotate slowly toward the subjects (off-axis viewing condition). Each subject held a button switch

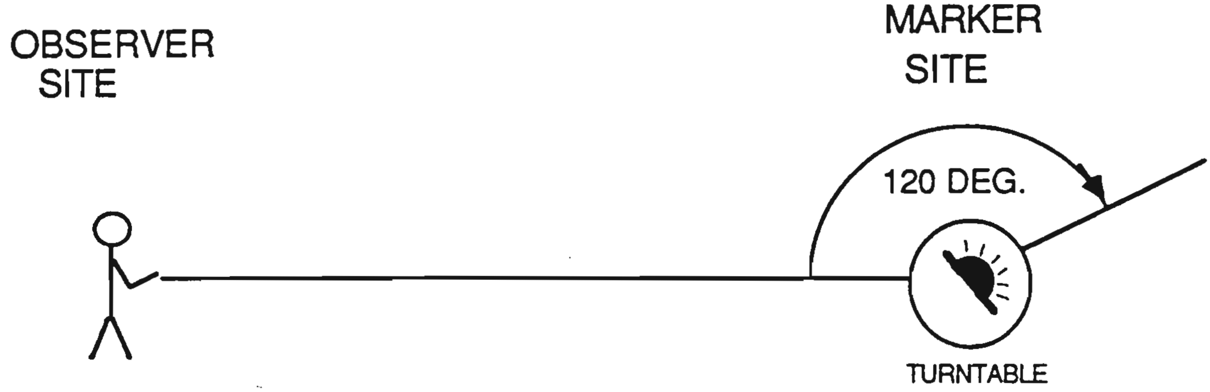

FIGURE 5-7. MARKER STARTING POSITION, RELATIVE TO SUBJECT

which was to be depressed when he/she first saw the light from the marker. They were cautioned against responding to reflections off surrounding objects such as trees, the ground, or signs. Each marker was presented in a block consisting of one practice trial (to acquaint the subjects with the marker characteristics) and three trials used for data collection. During the practice trial, the subjects depressed the button switches upon detection, but no data were collected. An audible click could be heard when a button switch was depressed; thus the subjects could be cued as to when someone else had detected a light. For this reason, they were cautioned to respond honestly, i.e., only when they had first detected the light from the marker. If, for some reason, the subjects felt that they had responded inappropriately or incorrectly, they informed the experimenter, the trial was declared a mistrial (no data recorded), and it was repeated.

Phase III: Pair Comparisons. Pairs of markers were simultaneously displayed, on-axis, to the subjects, for approximately 15-20 seconds. During this time, the subjects observed the markers, then indicated on a data sheet which marker of a pair was considered "more visible" and "more glaring." Every marker was compared against all of the other markers in the study, resulting in 28 pair comparisons. To facilitate ease of changing the markers being compared, a matrix of comparisons was devised so that the right marker of the pair to the right of the observers remained constant; the remaining markers were then displayed, in sequence, as the marker to the left of the observers. For example, Marker A was placed on the right side. On the left side, Markers B, C, D, E, F, G, and H were displayed in sequence (one at a time.) Next, Marker A was replaced by Marker B on the right side, and the remaining markers (C, D, E, F, G, and H) were displayed on the left side. The presentation schedules for the eight test sessions are shown in Figure 5-8.

All subjects were in the dark for at least 20 minutes prior to the start of the off-axis detection trials. In order to maintain this dark adaptation, throughout the test session, all van lights were kept off. However, the subjects were each equipped with a small penlight which was used when they recorded their responses on the rating forms.

GROUP 1:

	A	B	C	D	E	F	G	H
A	-	1	2	3	4	5	6	7
B		-	8	9	10	11	12	13
C			-	14	15	16	17	18
D				-	19	20	21	22
E					-	23	24	25
F						-	26	27
G							-	28
H								-

GROUP 2:

	B	C	D	E	F	G	H	A
B	-	1	2	3	4	5	6	7
C		-	8	9	10	11	12	13
D			-	14	15	16	17	18
E				-	19	20	21	22
F					-	23	24	25
G						-	26	27
H							-	28
A								-

GROUP 3:

	C	D	E	F	G	H	A	B
C	-	1	2	3	4	5	6	7
D		-	8	9	10	11	12	13
E			-	14	15	16	17	18
F				-	19	20	21	22
G					-	23	24	25
H						-	26	27
A							-	28
B								-

GROUP 4:

	D	E	F	G	H	A	B	C
D	-	1	2	3	4	5	6	7
E		-	8	9	10	11	12	13
F			-	14	15	16	17	18
G				-	19	20	21	22
H					-	23	24	25
A						-	26	27
B							-	28
C								-

GROUP 5:

	E	F	G	H	A	B	C	D
E	-	1	2	3	4	5	6	7
F		-	8	9	10	11	12	13
G			-	14	15	16	17	18
H				-	19	20	21	22
A					-	23	24	25
B						-	26	27
C							-	28
D								-

GROUP 6:

	F	G	H	A	B	C	D	E
F	-	1	2	3	4	5	6	7
G		-	8	9	10	11	12	13
H			-	14	15	16	17	18
A				-	19	20	21	22
B					-	23	24	25
C						-	26	27
D							-	28
E								-

GROUP 7:

	G	H	A	B	C	D	E	F
G	-	1	2	3	4	5	6	7
H		-	8	9	10	11	12	13
A			-	14	15	16	17	18
B				-	19	20	21	22
C					-	23	24	25
D						-	26	27
E							-	28
F								-

GROUP 8:

	H	A	B	C	D	E	F	G
H	-	1	2	3	4	5	6	7
A		-	8	9	10	11	12	13
B			-	14	15	16	17	18
C				-	19	20	21	22
D					-	23	24	25
E						-	26	27
F							-	28
G								-

FIGURE 5-8. PAIR COMPARISON PRESENTATION SCHEDULES

6.0 FIELD EXPERIMENTAL RESULTS AND DISCUSSION

Three types of measurements were collected from the subjects in this study. Subjects rated the visibility of the markers, one marker at a time, in a condition where they were situated 1000 ft from a marker and viewed the marker on-axis; this simulated a tangent track (0°) approach at 1000 feet. Under the same conditions, subjects were also presented with all unique pairs of the eight markers and were asked to make a forced-choice paired comparison of which member of each pair was most visible. The subjects' detection times during simulated approaches along an 11.5° curved track were also recorded in order to determine angles at which different markers could be first detected. The methods of analysis used and results obtained from the data are reported below.

6.1 Visibility Ratings

A five-point Likert scale was used to collect the visibility ratings from subjects. These ratings were then tabulated to determine the distribution of responses by subjects to the various markers. The visibility scale and results are presented in Table 6-1.

The following proportions of subjects rating the visibility of a given marker "Good" or "Very Good" are reported in Table 6-1:

Marker A (pulsed/yellow incandescent Star)	: $p = .833$
Marker B (pulsed/red LED Pulse)	: $p = .625$
Marker C (pulsed/yellow Xenon TCS)	: $p = .125$
Marker D (pulsed/red incandescent Star)	: $p = .958$
Marker E (steady/yellow incandescent Star)	: $p = .958$
Marker F (pulsed/red Xenon TCS)	: $p = .167$
Marker G (pulsed/red Xenon DSL)	: $p = .833$
Marker H (steady/red incandescent Star)	: $p = .958$.

TABLE 6-1. SUBJECT RATINGS OF REAR-END TRAIN MARKER VISIBILITY AT 0° 1000 FOOT APPROACH (N = 24).

Marker Visibility	Very Poor	Poor	Borderline	Good	Very Good
Marker A		1[a]	3	10	10
Marker B		4	5	9	6
Marker C	9	8	4	2	1
Marker D			1	12	11
Marker E			1	11	12
Marker F	6	10	4	2	2
Marker G			4	5	15
Marker H			1	10	13

a: Numbers indicate the frequency of a given response category by the subjects in the field test.

These proportions are each estimates of the true proportion, ϕ, in the population of human observers (represented by the subjects) who would rate a given marker's visibility as "Good" or better. Such an estimate for a proportion may be quite close to that true proportion but will practically ever actually equal it. This is due to a variety of reasons that collectively are referred to as sampling error. Because of this, confidence intervals are computed that offer a range of estimated proportion values with a specified probability (usually .90, .95, or .99) of containing the true population proportion value. The 95 percent confidence interval (CI) is commonly used and has been applied to the above data and represented in Figure 6-1. The formula used for these confidence intervals is given by Devore (1982, p. 330) as:

$$\phi = \left\{p + (z^2_{\alpha/2})/(2n) \pm [pq/n + (z^2_{\alpha/2})/(4n^2)]^{\frac{1}{2}}\right\} / [1 + (z^2_{\alpha/2})/n]$$

where ϕ = true population proportion
p = empirical proportion
$q = 1 - p$
$z^2_{\alpha/2}$ = the square of the standard normal deviate for $\alpha/2$
α = 1 - the confidence level, e.g., $\alpha = 1 - .95 = .05$
n = population number.

6.2 Pair Comparisons of Visibility

In addition to rating markers one at a time for visibility using the Likert scale, subjects were also presented with all 8(7)/2 = 28 unique pairs of the eight markers, and asked to make a forced-choice comparison of which member of each pair was most visible. This method of pair comparisons has proven to be extremely useful in human factors engineering because humans are especially good at making such simple relative judgments (Dunn-Rankin, 1983).

In this field test, the pair comparison procedure produced an 8x8 frequency matrix, F, with Markers A through H as rows and Markers A through H as columns. A cell corresponding to a given row and column of this matrix contained the number of subjects, out of 24, who judged the column marker to be more visible than the row marker. Elements of the F matrix were then

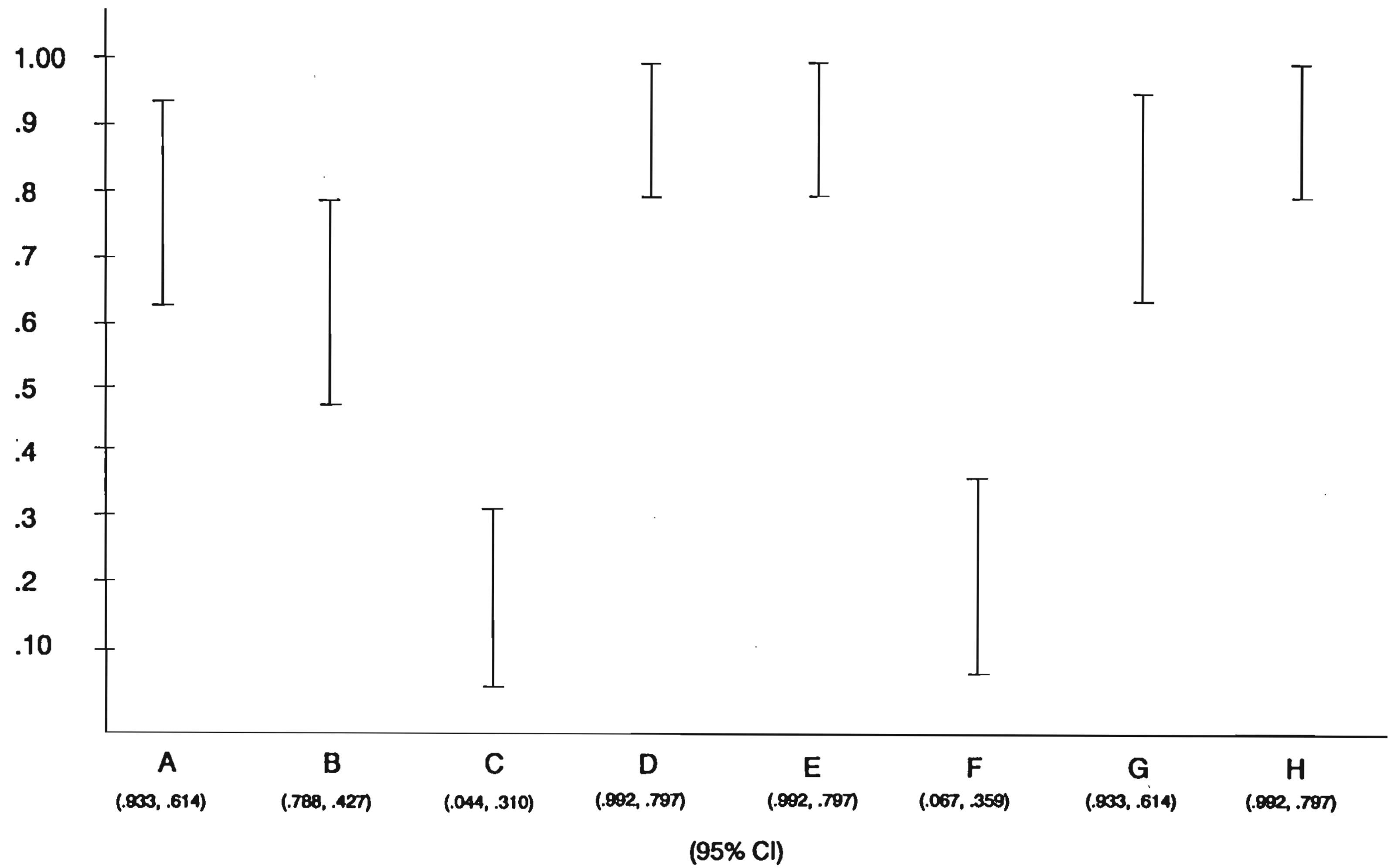

FIGURE 6-1. EMPIRICAL PROPORTIONS OF RATINGS FOR VISIBILITY "GOOD" OR "VERY GOOD", AND 95 PERCENT CONFIDENCE INTERVAL

divided by the total number of subjects and a matrix of proportions, P, was obtained. The matrix P is given in Table 6-2. (Proportions greater than .98or less than .02 have been rounded .98 and .02, respectively).

Note that the proportions in cell ji and cell ij of the P matrix must sum to 1. Note also the sum of column proportions given below the P matrix. These sums establish a rank order of visibility for the markers. The rank order of markers in terms of visibility is given here:

Best visibility	Marker E	steady/yellow incandescent Star
	Marker A	pulsed/yellow incandescent Star
	Marker H	steady/red incandescent Star
	Marker G	pulsed/red Xenon DSL
	Marker D	pulsed/red incandescent Star
	Marker B	pulsed/red LED Pulse
	Marker C	pulsed/yellow TCS
Worst visibility	Marker F	pulsed/red TCS.

Notice that the same markers suggested as "acceptable" from the rating data, are also at the top of the rank order given above.

A rank order indicates the relative position of objects on some dimension (visibility in this case) but does not indicate how far apart the ordered objects are from one another. In order to develop an interval scale for the rank ordered markers which indicates how close (or far apart) on the visibility continuum they are, additional assumptions are needed. A commonly used procedure for scaling pair comparison data is attributed to Thurstone (1927) and was applied here. The background for this type of scaling will be briefly described below to enhance understanding of results derived from it. The description of the method provided here borrows heavily from Dunn-Rankin (1983).

Thurstone postulated that for any stimulus, 1) people's reactions to that stimulus are subjective, and 2) they vary randomly from moment to moment. While reactions may vary, there is a most frequent reaction, called the modal reaction. This mode can be estimated based on repeated judgments from a single subject or, as in the present field test, the frequency of single judgments from many subjects. Thurstone further assumed these reactions were normally distributed. Because the mean and mode of a normal distribution are the same, the mean can serve as a scale value for an object (such as a train

TABLE 6-2. PROPORTION MATRIX, P, SHOWING THE PROPORTION OF SUBJECTS WHO JUDGED THE MARKER AT THE TOP TO BE MORE VISIBLE THAN THE EACH MARKER AT THE SIDE

MARKER	A	B	C	D	E	F	G	H
A	---	.125	.083	.292	.583	.042	.167	.583
B	.875	---	.042	.375	.792	.020	.583	.833
C	.917	.958	---	.980	.917	.250	.980	.980
D	.708	.625	.020	---	.833	.020	.500	.708
E	.417	.208	.083	.167	---	.417	.167	.167
F	.958	.980	.750	.980	.958	---	.980	.917
G	.833	.417	.020	.500	.833	.020	---	.652*
H	.417	.167	.020	.292	.833	.083	.348*	---
								---1
Σp_j	5.12	3.48	1.02	3.59	5.75	0.85	3.72	4.84

Note: $\Sigma p_j > p_i$

Cells marked *, n = 23 due to missing data (n = no. subjects).

marker) on the psychological continuum of interest, in this case, a visibility continuum.

In the field study, subjects were asked to judge which of two markers was more visible for all pairs of markers. Using pair comparisons, the proportions recorded in Table 6-2 were collected. If, as indicated, 83 percent of subjects judged Marker H to be more visible than Marker B, then according to Thurstone, the average reaction to Marker H should be higher on a visibility scale than the average reaction to Marker B. Because of the normality assumption mentioned above, proportions can be expressed as standard normal deviates, e.g., in the example, the normal deviate is $z_{BH} = .97$ (for $p = .833$), obtained from a standard normal table. This has been done in Table 6-3. The scale separation between Marker H and Marker B on a visibility continuum can be made in terms of this standard normal deviate, i.e., somewhere along this continuum, Markers H and B are separated by a distance of .97, with Marker H higher on the visibility scale.

The differences between pairs of markers can be obtained by use of the normality assumption. In practice, the average z-score for column markers is computed (see Guilford, 1954, pp. 161-163) and this provides an interval scale of visibility (see bottom of Table 6-3). Because interval scales have arbitrary origins (like the various temperature scales), the z score averages can be rescaled for convenience to be greater than or equal to zero simply by assigning the smallest (or most negative) value to be zero and shifting all other scale values up accordingly. The result is graphically presented in Figure 6-2. It can be seen that Markers A, E, and H are relatively close together in terms of visibility. Markers D and G are close to each other and some distance below Markers A, E, and H on the visibility continuum. Marker B is relatively close to Marker D and G also. Finally, Markers F and C are close together, somewhat removed from the other markers on the scale, and are relatively far down toward the negative end of the continuum.

6.3 Detection Angles from Simulated Approach along an 11.5° Track

Visual performance data were collected to determine how easily observers would detect a marker during a slow, curved track approach. In

TABLE 6-3. THE STANDARD NORMAL DEVIATE MATRIX, Z, SHOWING THE PROPORTION OF SUBJECTS WHO JUDGED THE MARKER AT THE TOP TO BE MORE VISIBLE THAN THE EACH MARKER AT THE SIDE

MARKER	A	B	C	D	E	F	G	H
A	0.0	-1.15	-1.39	-.55	.21	-1.72	-.97	.21
B	1.15	0.0	-1.72	-.32	.81	-2.06	.21	.97
C	1.39	1.72	0.0	2.06	1.39	-.67	2.06	2.06
D	.55	.32	-2.06	0.0	.97	-2.05	0.0	.55
E	-.21	-.81	-1.39	-.97	0.0	-.21	-.97	-.97
F	1.72	2.06	.67	2.06	.21	0.0	2.06	1.39
G	.97	-.21	-2.06	0.0	.97	-2.06	0.0	.39
H	-.21	-.97	-2.06	-.55	.97	-1.39	-.39	0.0
Σz	5.36	.96	-10.01	1.73	5.53	-10.16	2.00	4.60
$Mean_z$	.67	.12	-1.25	.22	.69	-1.27	.25	.58

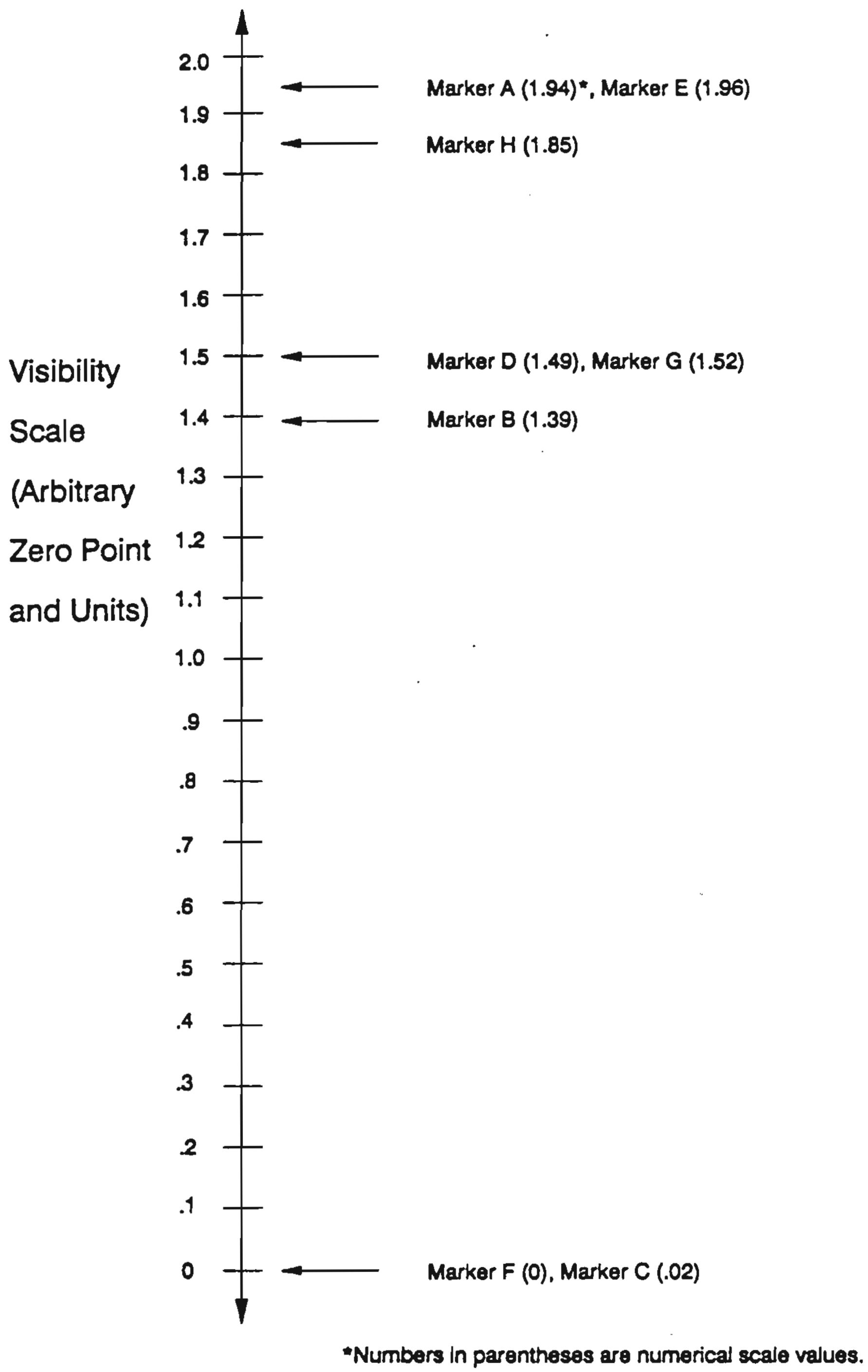

FIGURE 6-2. THURSTONE CLASS V INTERVAL SCALE OF REAR-END TRAIN MARKER VISIBILITY, 1000' TANGENT TRACK CONDITION

keeping with the best case/worse case analysis, an 11.5° curve approach was simulated (see Appendix A for further explanation) to represent the most extreme curve which would be encountered in operation.

The median of three data trials for each subject for each marker served as the data for analysis of detection angles. The median was chosen as the summary statistic for each subject's data because, especially for small samples with possible outliers*, the median provides a better estimate of the population mean than does the sample mean. However, since the population characteristic estimated is mean detection angle, it is still reasonable to test hypotheses about means of medians.

Table 6-4 presents the means, across subjects, of the median detection angles for Markers A through H. All of the detection angles reported in Table 4.4 are considerably greater than 57.3°. This implies that all markers are acceptable because they all afford at least 1000 ft of stop-ping distance on an 11.5° curved track (under the field test conditions). The Star markers were detected most readily in part because they had a lens design that protruded sufficiently beyond the edge of the reflector housing so as to allow detection at angles substantially greater than 90°. TCS markers also had lenses that protruded beyond their marker housing, though not as much as the Star markers. The side views of the various markers used in this field test are shown in Figure 6-3.

Even though all markers were equally acceptable according to the 1000 ft stopping distance criterion, there were statistically reliable differences among them. These differences are noted in Appendix E. Certain observations regarding marker characteristics are appropriate at this point. Colors indicated by the labels "red" and "yellow" do not rigorously define marker chromaticity. (See Table 4-1, page 12, for spectral data on the markers used in the field test). Rather, these labels simply stand for a range of subjective impressions which most people would call "red" or "yellow". Similarly, cycle (i.e., pulsed or steady) does not capture such design parameters as pulse width, pulse period, shape of the rise or decay function, et cetera. These too are labels which capture the subjective

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* An outlier is an extreme observation, well beyond a normal distribution.

TABLE 6-4. MEAN PER MARKER, ACROSS SUBJECTS, OF MEDIAN DETECTION ANGLES, IN DEGREES

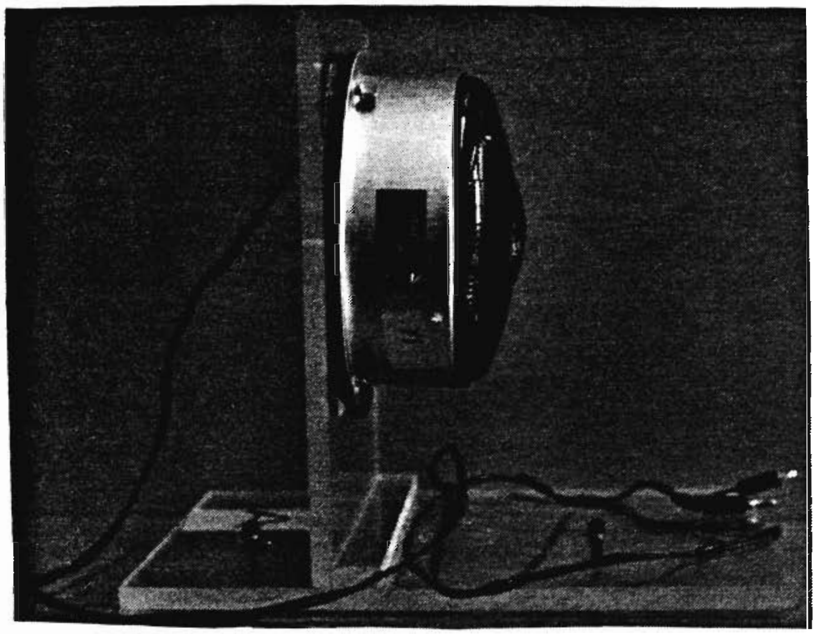
Mean Angle[a]	Range[c]	Code	Color	Cycle	Lamp Type	Mfg.
154.72 (4.97)[b]	(145.0, 169.6)	A	yellow	blink	Incandescent	Star
83.77 (3.34)	(77.8, 90.4)	B	red	blink	LED	Pulse
91.34 (1.63)	(87.7 94.7)	C	yellow	blink	Xenon pulse	TCS
160.40 (3.05)	(147.6, 163.1)	D	red	blink	Incandescent	Star
164.14 (2.88	(159.7, 169.7)	E	yellow	no blink	Incandescent	Star
85.98 (3.80)	(75.0, 92.4)	F	red	blink	Xenon pulse	TCS
85.30 (1.65)	(82.7, 88.6)	G	red	blink	Xenon pulse	DSL
156.88 (3.12)	(149.3, 163.0)	H	red	no blink	Incandescent	Star

Notes:

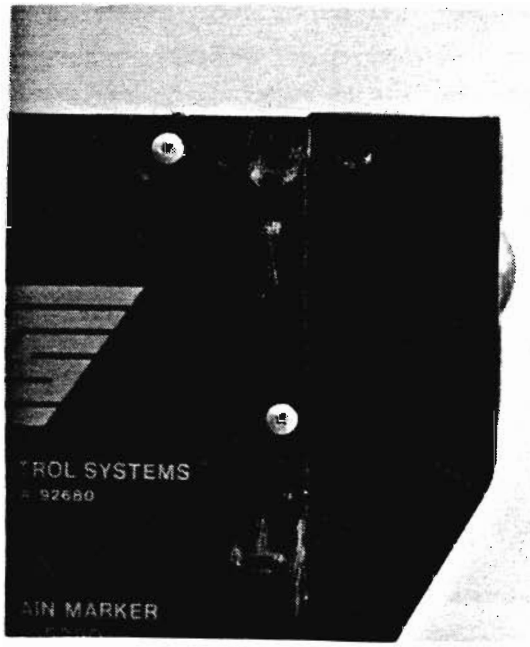
a - All angles are given in degrees from the observer.

b - Numbers in parentheses are standard deviations.

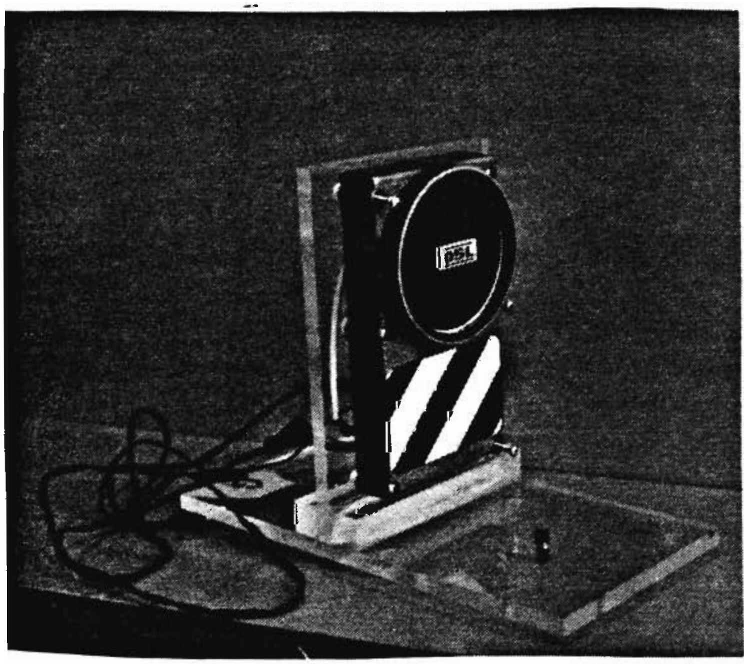
c - Ranges indicate the minimum and maximum detection angles found during the field test.



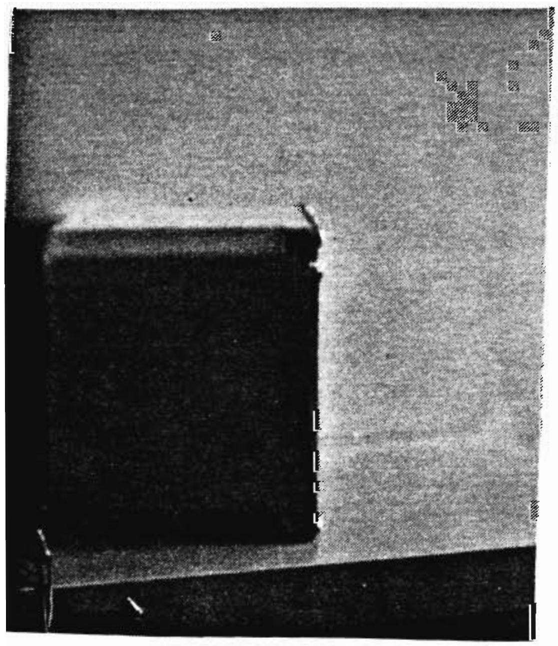
A. Star Marker



B. Transit Control Marker



C. DSL Marker



D. Pulse Marker

FIGURE 6-3. SIDE VIEWS OF REAR-END MARKERS USED IN TESTS

impression of whether a given light source blinks or remains steady. With the understanding that they are qualitatively defined, tests of the effect of color and cycle on detection angles were conducted.

In order to assess the impact of color on mean detection angles, an analysis was conducted on blinking red and yellow Star and blinking red and yellow TCS markers. This analysis seemed reasonable because the manufacturer of a marker was analyzed as a separate variable of two levels (Star and TCS). This allowed for the separation of effects due to color and effects due to factors other than color which were collectively referred to as differences due to manufacturer. The factor of color was also of two levels (red, yellow).

Table 6-5 presents the results of the field test in a contingency table with levels of color as columns and levels of manufacturer as rows. Means for red and yellow markers, averaged over both marker manufacturers, were not statistically different. Means for Star and TCS markers, averaged over red and yellow, were statistically different. There was also a significant Color times Manufacturer interaction. These differences are noted in Appendix E.

There was a big difference found between manufacturers. This main effect is not surprising, given the results reported in Table 6-4. The interaction suggests that the impact of color on detection angle depended on the manufacturer of the marker. The yellow TCS marker was more readily detected than the red TCS marker (means of 91.3° and 86.0°, respectively). For the blinking Star markers, the reverse was true (means of 160.4° and 154.7°, respectively, for blinking red and yellow markers).

Another marker design variable of interest is cycle (blink vs. no blink). Within the conditions of this field test, the Star lamps offered an opportunity to test for the effects of cycle and investigate any interaction which might exist between color (red, yellow) and cycle (blink, no blink). (Star markers were used for this analysis because only Star markers came in both red and yellow, both blink and no blink). The results from the field test are summarized in Table 6-6. Analysis of variance indicated no signifi-

TABLE 6-5. CONTINGENCY TABLE OF MEAN DETECTION ANGLES, COLOR (RED, YELLOW) BY MANUFACTURER (PULSED STAR, TCS)

Manufacturer	Detection Angle vs. Color		
	Red	Yellow	Row Means
Star	160.4°	154.7°	157.5°
TCS	86.0°	91.3°	88.6°
Column Means:	123.2°	123.0°	

TABLE 6-6 CONTINGENCY TABLE OF MEAN DETECTION ANGLES BY COLOR (RED, YELLOW) AND CYCLE (PULSED, STEADY), STAR MARKERS

Light Cycle	Detection Angle vs. Color		
	Red	Yellow	Row Means
Steady	156.9°	164.1°	160.5°
Pulsed	160.4°	154.7°	157.5°
Column Means:	158.6°	159.4°	

cant main effect of color. Similarly, there was no main effect for cycle. There was, however, a significant interaction between color and cycle. These effects are noted in Appendix E.

No other tests were conducted on this data because of confounding factors which would have made interpretation impossible.

6.4 Discussion of Results

The results of the field test address both on-axis viewing of the markers at 1000 ft (through subjective assessments of visibility) and off-axis detection in a simulated approach along an 11.5° track (through visual performance). It is important to keep in mind that the results reported above and the discussion of those results given apply most directly to conditions like those of the test. These conditions included excellent atmospheric transmissibility (i.e., no rain, fog, snow) clean and properly functioning markers, alert subjects undistracted by any other workload, a relatively uncluttered test environment, and no veiling reflections from a locomotive headlamp. These factors deserve analysis, but due to the complexity and considerable time involved, an analysis of these factors was outside the scope of this field test. Therefore, extrapolation from the current results (which might be considered a baseline under near ideal conditions) must be made cautiously.

6.4.1 Subjective Ratings, Rankings and Scaling of Rear-End Train Marker Visibility

Consider first the results of the visibility ratings. In interpreting the confidence intervals given in Figure 6-1, recall that the conditions of the field test were virtually ideal. Furthermore, consider also that people were asked to use their own subjective (and presumably reasonable) criterion of a marker's visibility, i.e., the ease with which the marker may be seen. Given that actual operating conditions will not always be so ideal, it seems prudent to be concerned about markers that would be judged less than "Good" by most people. The cutoff defining "most people" is somewhat arbitrary, but it seems that, adopting the most lax criterion, the confidence interval for the proportions of "Good" or "Very Good" ratings for a marker should not extend below .50. (A true proportion of ϕ = .5 indicates that half the observers in the population would judge a marker's visibility "Borderline" or worse). Using this criterion, the following markers seem to offer adequate visibility: Marker A, D, E, G, and H, i.e., all Star markers and the DSL marker. The cutoff can be varied, of course, to more stringent or more lenient levels.

A criticism of the above arguments may be that, in fact, all subjects in the field test saw all markers at 1000 ft, thereby meeting the FRA's suggested stopping distance criterion. However, the fact that the field test was conducted under near ideal conditions suggests caution about markers judged by a substantial proportion of people to be less than good. The 95 percent Confidence Interval with 0.5 cutoff criteria is one attempt to quantitatively define this concern in terms of a decision rule.

Consider next the rankings and scaling results. The ratings, taken with reference to each subject's own standard of "the ease with which a marker may be seen", did provide some indication of the acceptability of various markers with respect to visibility under the conditions of the field test. However, the rating data did not really provide a comparison among markers. Ranking does, but it only shows the relative position on an ordered list of the rear-end train markers. It provides no information on how different the markers might be from one another or whether specific markers are above or below an acceptability threshold for visibility. Scaling provides additional information about the relative distance between markers on the visibility continuum, but also does not indicate the acceptability of marker's visibility.

Thus, ratings, rankings, and scaling analyses complement one another in helping to understand the perceived visibility of rear-end train markers under the conditions of the field test reported here. Taken together, the conclusion is that, based on the subjective assessment data collected under the conditions of the field test, Markers A, D, E, G, (the Star markers) and H (the DSL marker) should be quite visible under operational conditions similar to those of the field test. On the other hand, even though all markers were visible to all subjects, ratings, rankings, and scale values suggest that the visibility of Marker B (the Pulse marker) is relatively borderline, and markers C and F (TCS markers) under less than ideal conditions are suspect. All of these conclusions are intended to apply only to slow approaches on a tangent (straight) track with detection at 1000 ft; as an observer approaches closer and closer to a marker, its visibility will presumably increase.

6.4.2 Discussion of Detection Angle Results from Simulated Approach Along an 11.5° Curved Track

The most important result of the detection angle data is that all detection angles were greater than the 57.3° needed to afford at least 1000 ft of track stopping distance during a slow approach along such a curved track. This implies that all markers tested were acceptable with respect to this criterion.

Simple tests of marker manufacturer (Star and TCS) and marker color (red, yellow) were made to assess the impact color had on off-axis detections. Results (see Table 6-4) indicated that, as expected, manufacturer differences were significant (i.e., Star markers were detected more readily than TCS markers). However, there was a manufacturer times color interaction such that blinking yellow TCS markers were detected more readily than blinking red TCS markers; the reverse was true for Star devices. A plausible (though incomplete) explanation for this interaction is offered in terms of the design differences between Star and TCS markers.

Consider first the physical design of the markers (see Figure 6-3). The housing of a TCS marker exposed less of the lens to an observer than the design of the Star markers at any given viewing angle of 90° or greater. This must have contributed to later detection time with the TCS markers. **A design implication is that the more a marker lens protrudes beyond the reflector housing, the more readily it may be detected during approaches on curved track.**

A second factor contributing to the interaction between manufacturer and color may be due to differences in brightness. Subjective impressions were that the TCS markers were dimmer than the Star markers and this may be explained by Bloch's law (Shiffman, 1976). Bloch's Law says that, for durations of about 100 milliseconds or less, the product of stimulus intensity (I) and stimulus duration (t) equals a constant (K) which is related to perceived brightness, i.e., I x T = K. Beyond 100 msec, perceived brightness is a function of stimulus intensity alone. In the present case, the pulse width of the TCS markers was considerably shorter (around 25 nanoseconds) than that for the Star markers (around 250 milliseconds) over roughly the same pulse period (1 second for each make). The reciprocal relationship between intensity and blink duration given in Bloch's Law implies that the greater peak intensity of TCS Xenon lamps was undermined by a pulse width which was too short. This lowered the apparent brightness of the TCS lamps to a level where the higher luminance of TCS yellow over TCS red was significantly advantageous to off-axis detection. **The design implication of this is that pulse periods and peak intensities must both be defined in relation to one another to support a specified level of visual performance.**

The explanation of why blinking red Star markers were detected more readily than blinking yellow Star markers is unknown at this time. A check of the data indicated the superiority of blinking red markers was quite pronounced: twenty-two (22) out of twenty-four subjects detected it more readily than the blinking yellow marker.

Another test was conducted to compare the impact of cycle (blink, no blink) and color (red, yellow) on off-axis detection performance (for the Star markers only). As indicated in Table 6-6, blinking red Star markers were detected more readily than steady red Star markers, but the opposite effect was observed for the yellow markers: steady yellow Star markers were detected more readily than blinking yellow Star markers. Blink is commonly used to enhance the detectibility of a light source, especially when that source is relatively dim, to be viewed at night, or likely to be viewed with peripheral vision. In the present case, the red Star markers were dimmer than the yellow markers (see Ross and Grieser, 1988). One possible explanation is that they were of such a luminance that the added visual 'motion' of blink significantly helped make the blinking red markers more detectible than steady red markers.

What is there, then, to explain the opposite pattern of results with the yellow Star markers which were relatively brighter than the red ones? One tentative explanation is that blink may have simply reduced the overall apparent brightness of the blinking yellow marker when compared to a steady yellow marker. There is evidence (e.g., Talbot's Law) that the visual system averages the amount of total luminance received during light and dark phases of a blink cycle (Shiffman, 1976). A steady light would therefore be perceived as brighter than a blinking one, under the proper conditions. The Thurstone scaling data also showed that steady lights were of consistently (though slightly) better visibility. The Star color x blink interaction, then, suggests a compromise on design. **If actual train operations will involve an observer first detecting a rear-end train marker with peripheral vision, it may be most effective to use a yellow marker such as the Star (for greater brightness than the corresponding red Star marker provides) but include blink (to provide visual motion).**

As was mentioned previously, no other tests were conducted on this data because of confounding factors which would have made interpretation impossible. All explanations offered above must be considered hypothetical only. Alternative explanations may also be available.

6.4.3. The Effects of Glare from Rear-End Train Markers

One factor of interest in evaluating rear-end train markers is the glare that they may cause. Direct glare from markers can be discomforting, impair visual performance, or both. Unfortunately, an assessment of the glare properties of the markers used in the field test was beyond the scope of this study. This is because the effects of a direct glare source are a complex function of several variables. A primary variable is distance to the source. Almost any bright light source can become glaring as one approaches it, not because it is getting brighter but because it is visually looming to assume a larger and larger proportion of the visual field. Another primary variable is the vertical difference between the marker and the observer's line of sight; the marker, located at coupler height, is much lower than the locomotive engineer seated in the cab. As the observer approaches in a locomotive, however, the marker begins to drop below the observer's line of sight such that when a locomotive is located immediately behind the train, the marker will be well below the observer's line of sight. When one considers further that glare is a function of the visual system's state of light/dark adaptation, presence of other light sources in the background, and involves both discomfort and disability, an analysis of glare properties is a study unto itself. It is for this reason that no glare assessment data are included in this report. Such a study might plot discomfort glare (which is subjectively determined) as a function of distance to the marker. It might also assess any disability caused by means of a visual test.

7.0 SUMMARY AND CONCLUSIONS

7.1 Laboratory Tests

Laboratory tests were conducted on the train rear-end marker devices from four manufacturers. Chromaticity (color) measurements were made for each device to determine irradiance versus wavelength over a range from 380 to 780 millimicrons. Peak intensity measurements were made using a telephotometer at distances of 25 and 100 ft, both on the geometric center and ±90° from this center on the horizontal and vertical axes. For the pulsed lamps, effective intensities were calculated from peak intensities and integrating the pulse shape versus time, and using the appropriate formula from the IES Lighting Handbook.

Results from these tests showed that all units met the FRA color range requirements. For the slower pulsed units (Pulse, Star -- typically a 1/4 second pulse duration), peak intensities on-axis exceeded the FRA minimum of 100 candela. Off-axis (±15° horizontally, ±5° vertically), the Pulse devices fell near or below the FRA minimum of 50 candela; while the Star devices (particularly with the amber lens) exceeded the minimum. Effective intensity for these units (in candela-seconds), based on the IES formula, fell below the given minima, except for the Star units with amber lense.

For the xenon flash tube devices (DSL, TCS -- typically a 20 micro-second pulse duration), peak intensities exceeded the FRA maximum of 1000 candela. Effective intensities for the DSL units exceeded the FRA minimum of 100 on axis, but fell below the FRA minimum of 50 off axis. Effective intensities for the TCS units fell below 1.0, a factor greater than 100 below the FRA minimum.

Comparison of these test results with tests conducted by ETL Testing Laboratories, Inc., on the same or similar devices showed that Battelle's peak intensity measurements were substantially lower than ETL's. Direct comparison of measurements with both sets of equipment on three of the devices, using the same set-up procedures, showed good correlation between results. Based on this comparison, we conclude that the major differences in intensity values are the result of device mounting. Where Battelle chose the geometric center for its measurements, ETL chose the lamp "hot spot" (point of maximum intensity) for its readings. In future testing, the device mounting protocol must be taken into consideration so that consistency in results may be achieved.

7.2 Field Tests

A field test was conducted to assess the visibility to human observers of a sample of rear-end train marker differing in lamp type, color, cycle (pulsed or steady) and luminance. Both subjective assessments and visual detection data were collected. The following is a summary of results and conclusions with respect to visibility of the markers tested:

1. All markers used in this field test afforded adequate off-axis detection, under the conditions of the test, using the 1000 ft track stopping distance criterion;

2. All markers used in this field test were visible to all subjects in a 1000 ft on-axis viewing condition which simmulated an approach on tangent track;

3. Despite the equality of markers with reference to an acceptable/unacceptable threshold for affording at least 1000 ft of track stopping distance upon detection during a 15-mph slow approach, field test data did distinguish among markers.

4. If markers are ranked in order of off-axis detectibility based on mean detection angles, the following list emerges, in terms of first detected:

Marker E	Star, Yellow/steady (incandescent)	-- 164°
Marker D	Star, Red/pulsed (incandescent)	-- 160°
Marker H	Star, Red/steady (incandescent)	-- 157°
Marker A	Star, Yellow/pulsed (incandescent)	-- 155°
Marker C	TCS, Yellow/pulsed (Xenon flash)	-- 91°
Marker F,	TCS, Red/pulsed (Xenon flash)	-- 86°
Marker G,	DSL, Red/pulsed (Xenon flash)	-- 85°
Marker B,	Pulse, Red/pulsed (LED)	-- 84°

5. Using the off-axis detection test conditions, Star markers were far more readily detected than any of the other makes. When corrected for the fact that 90° is the largest viewing angle of practical interest, the Star markers are still the best, but their superiority is reduced substantially.

6. Color effects on off-axis detection were not simple. Given blinking markers such as the TCS Xenon devices, yellow seems to offer an advantage over red. For markers such as the blinking Star devices, red seems to offer an advantage over yellow.

7. Similarly, color and cycle (pulsed or steady) do not have simple effects with markers such as the Star lamps. Under the off-axis detection conditions of the test, blinking red markers were detected earlier than steady red markers. However, steady yellow markers were detected more readily than blinking yellow markers.

8. Subjective evaluations of visibility (ratings, rankings, and scaling of the markers) differentiated among the markers: Star and DSL markers were judged most visible of the lot tested.

9. The marker indicated by the field test data as being most readily detectible in both straight and curved approach conditions is the Star, yellow/steady incandescent marker.

10. If actual train operations will involve an observer first detecting a rear-end train marker with peripheral vision, it may be most effective to use a yellow marker such as the Star (for greater brightness than Star red provides), but include blink to provide attention-catching visual motion for an observer who may be distracted by other duties.

11. This field test was conducted under near ideal environmental and observer conditions. It is most properly considered a baseline comparison of a sample of rear-end train markers. Effectiveness of the markers under varying conditions of atmospheric transmissibility (fog, rain, snow), dirt buildup on the lens of the markers, obscurants on the cab windshield, clutter in the visual field, high workload on the observer, etc. were not evaluated. These were considered to be outside the time and budget resources of this contract.

12. Under the conditions of the test, all markers are acceptable from the standpoint of the visual performance criteria mentioned above. This suggests other, non-visual, criteria be used for distinguishing among markers, if necessary. These criteria might include cost, reliability, availability, and maintainability. Alternatively, the results suggest that several different designs of rear-end train markers will be acceptable from a human factors standpoint.

7.3 Recommendations for Future Research

The following recommendations for future research are offered to the Federal Railroad Administration (FRA) for their consideration. It is believed that projects such as those listed below will contribute to a better understanding of active rear-end train marker technology from the standpoint of human observers. The following studies are recommended:

1. An archival study to compile existing guidelines on the design of rear-end train markers (and similar devices). Such a study would review existing literature to collect useful guidance on design parameters which yield superior markers and signage. Sources would include literature in visual science, psychology, human factors, special studies conducted in the transportation arena (rail, air, sea, and road), DOD standards and guidelines, foreign standards and guidelines, etc. This resulting guidelines manual could support revisions of the Code of Federal Regulations, Part 221 as well as suggest gaps in understanding of marker design. It is anticipated that such a manual would be useful in other areas of DOT as well.

2. A study of the nature of glare associated with active rear-end train markers similar to the one briefly described in Section 6.4. An enhanced understanding of glare effects associated with rear-end train marker devices would provide data to guide the design or selection of markers which are acceptable to railroad engineers and enhance railroad safety.

3. An assessment of factors which may constrain the applicability of the results reported in this field test. Such factors as observer workload, obscurants, headlamp effects, visual clutter, and locomotive engineer preferences might be addressed in such research.

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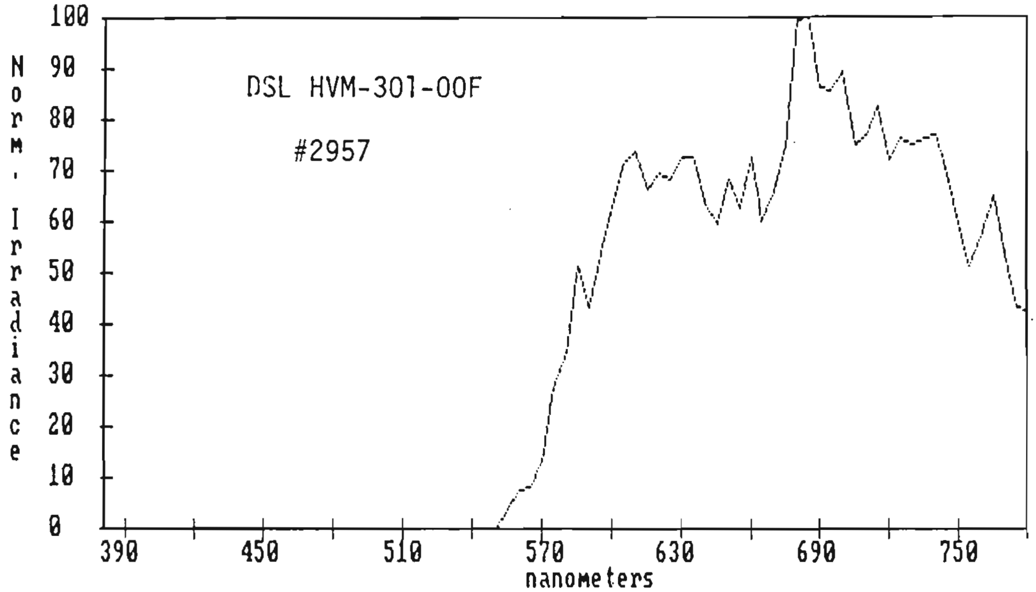
APPENDIX A

SPECTRAL DATA



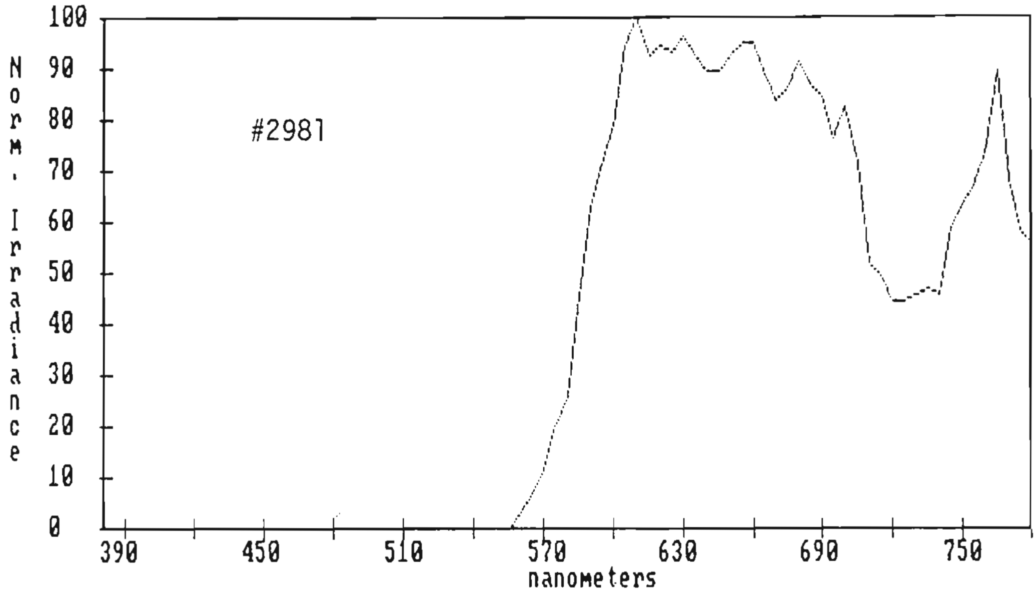
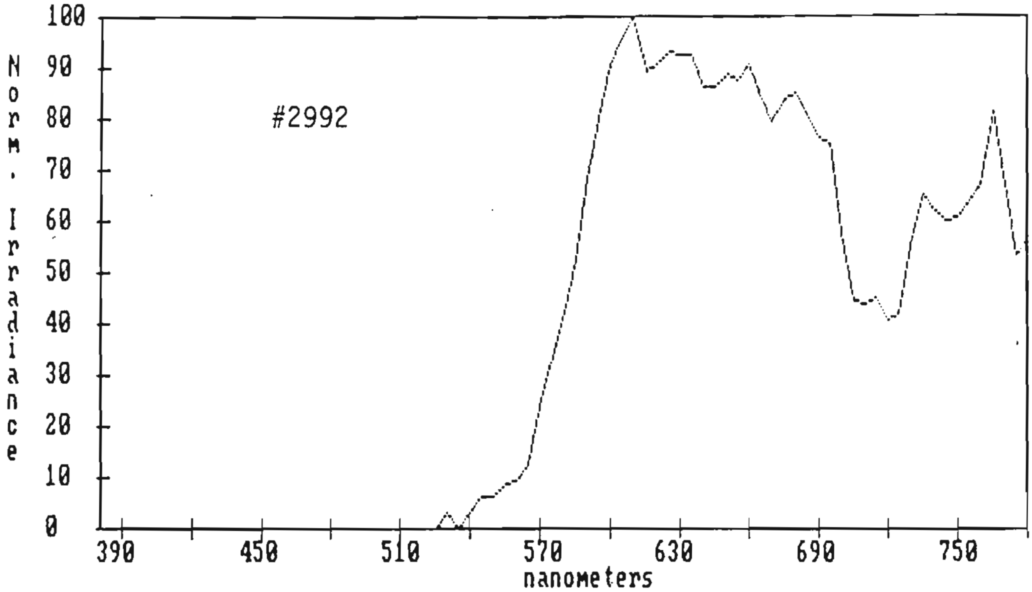


FIGURE A-1. SPECTRAL RESPONSE OF DSL REAR-END MARKER DEVICES



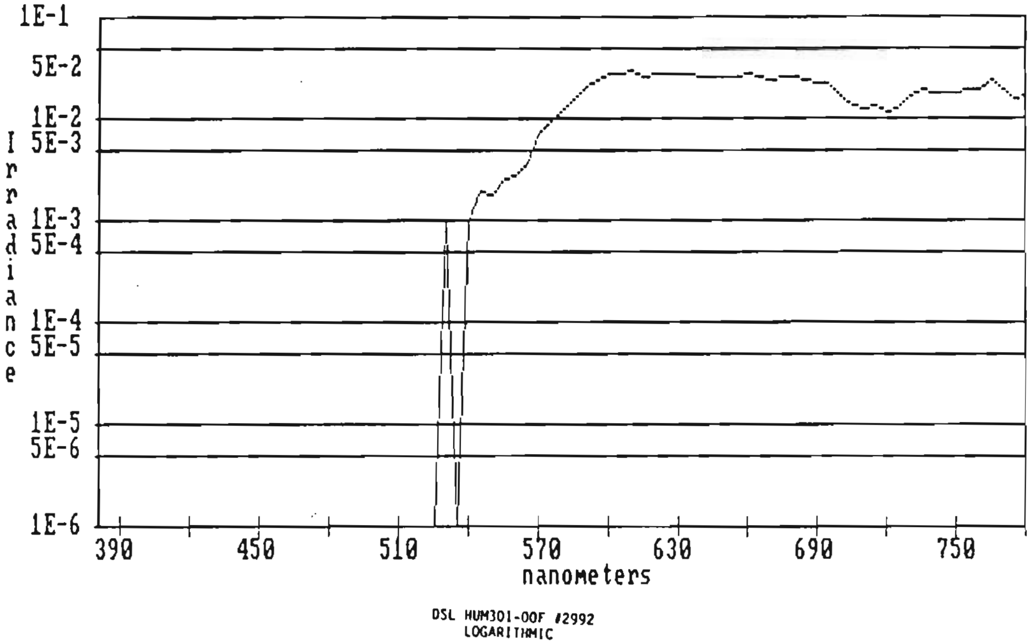
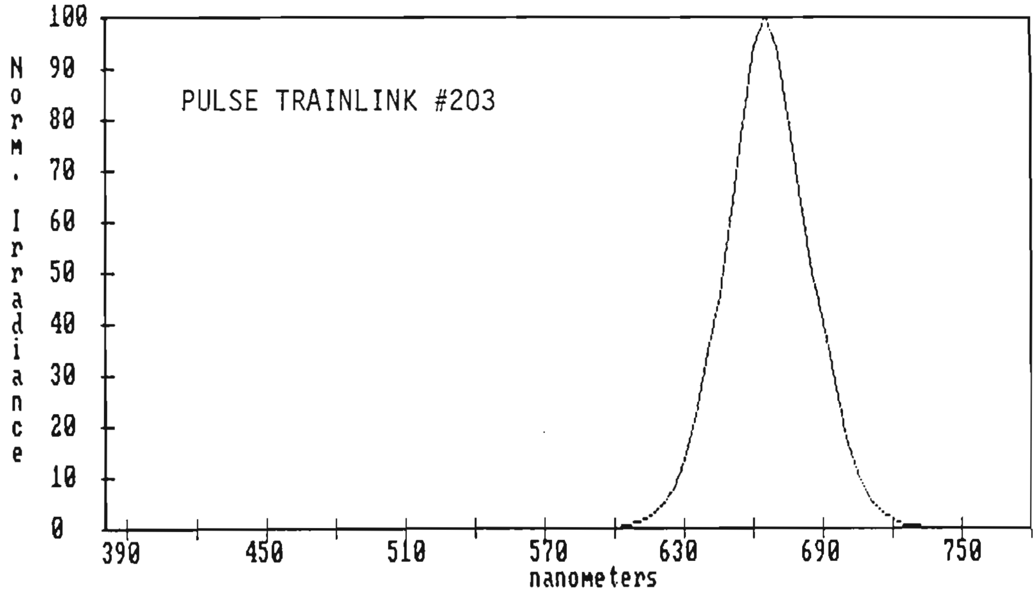


FIGURE A-1. (continued)



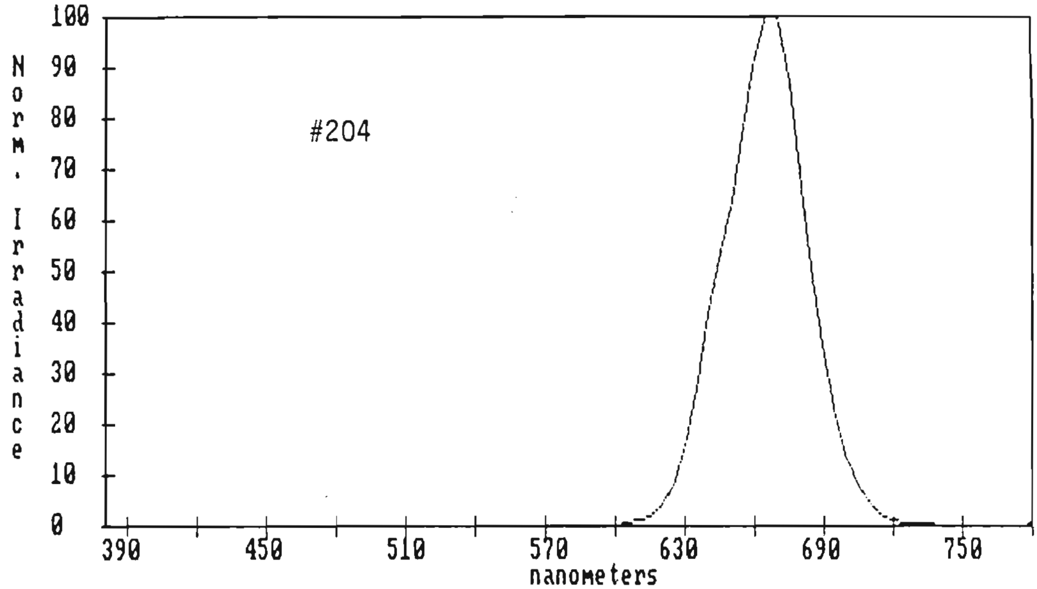
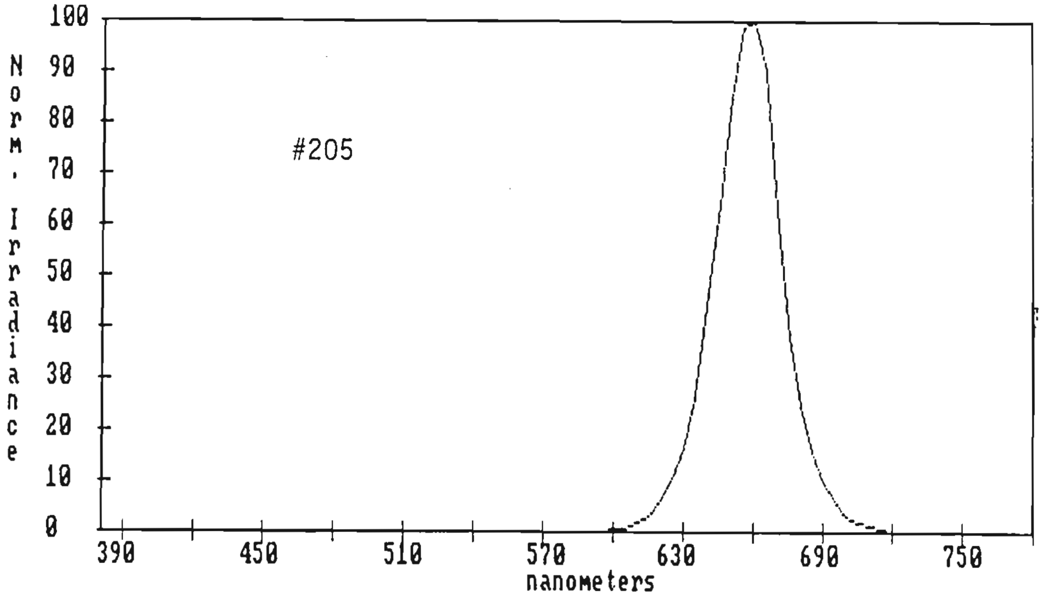


FIGURE A-2. SPECTRAL RESPONSE OF PULSE REAR-END MARKER DEVICES



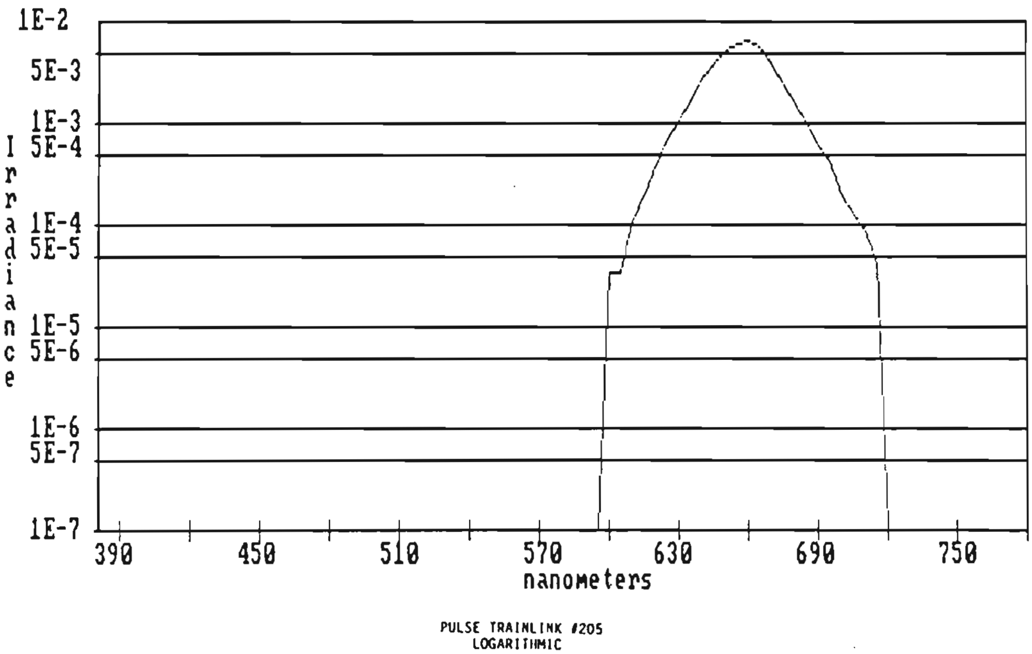


FIGURE A-2. (continued)

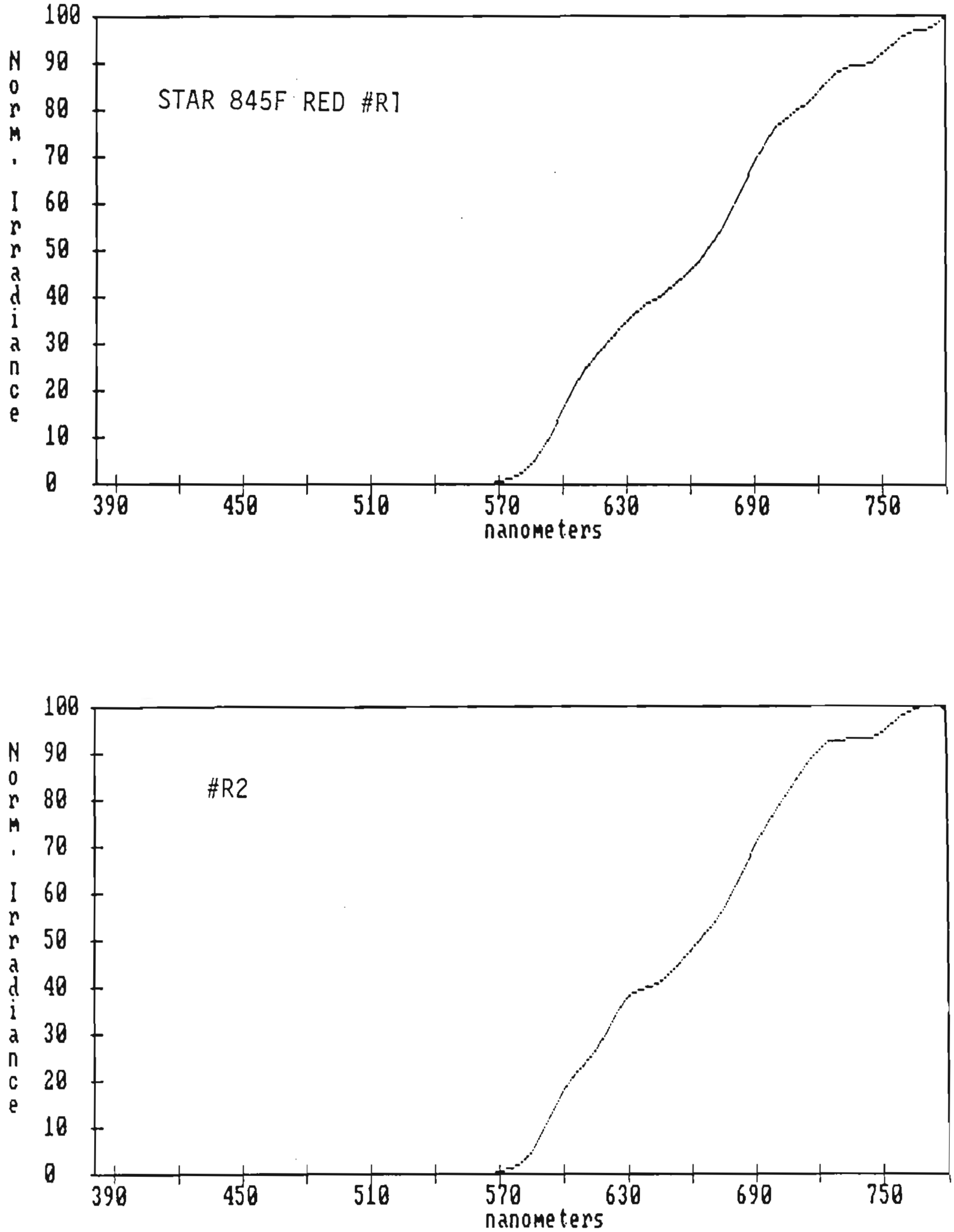
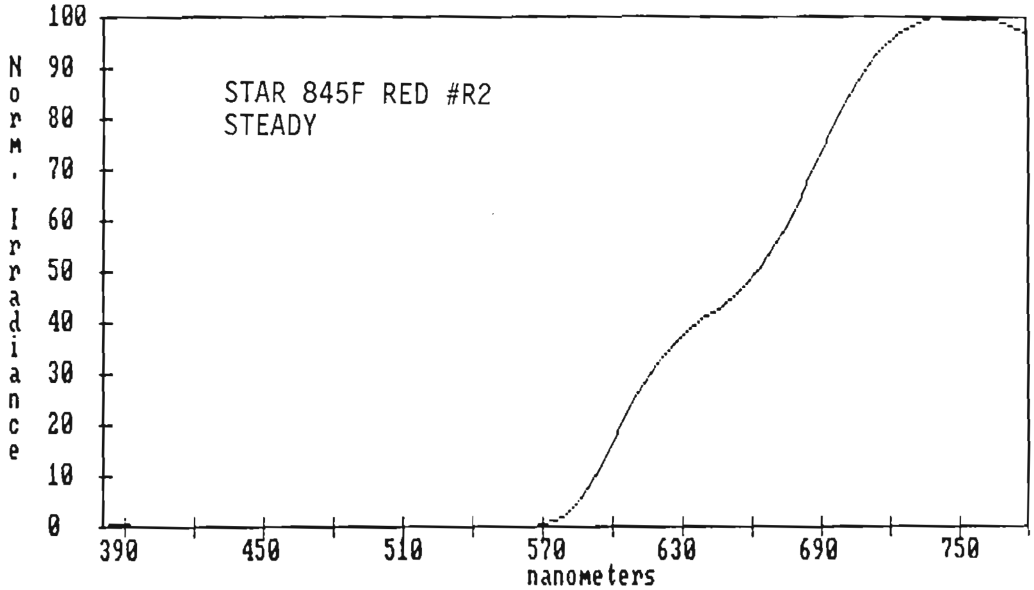
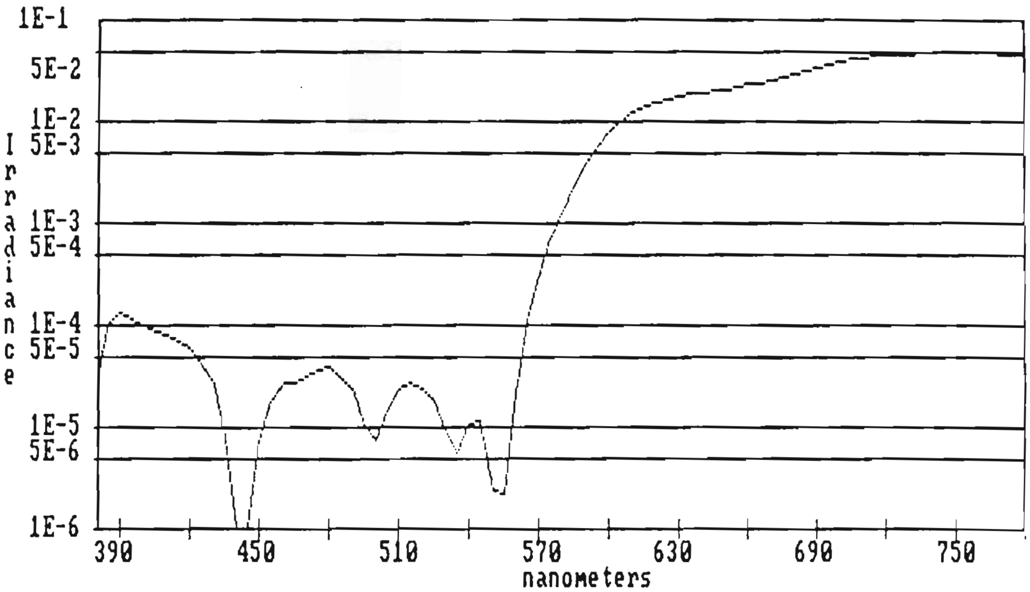


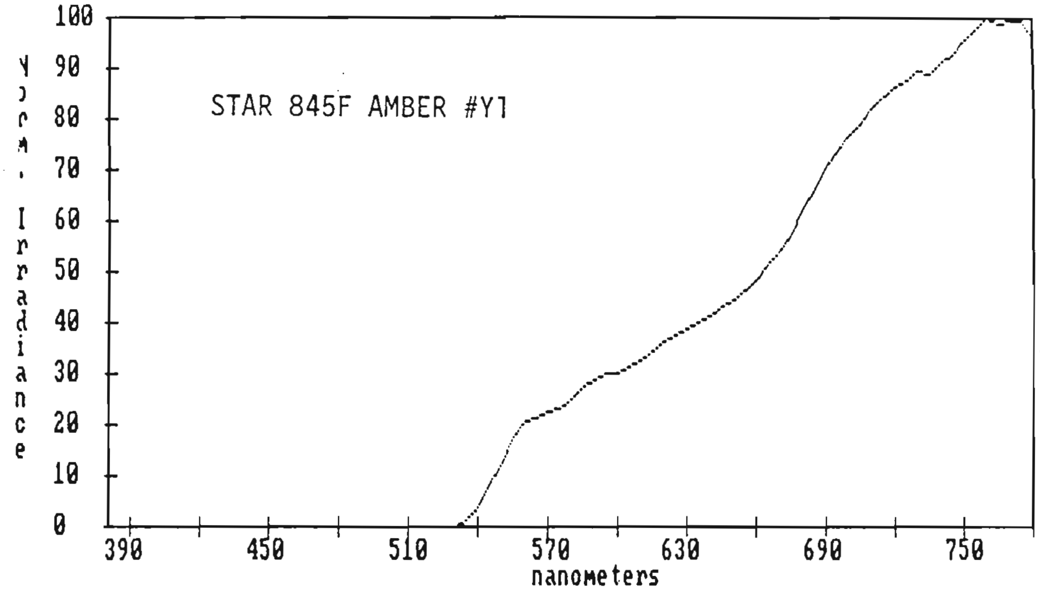
FIGURE A-3. SPECTRAL RESPONSE OF STAR MARKER DEVICES, RED LENSE





STAR 845F RED #R2, STEADY STATE
LOGARITHMIC

FIGURE A-3. (continued)



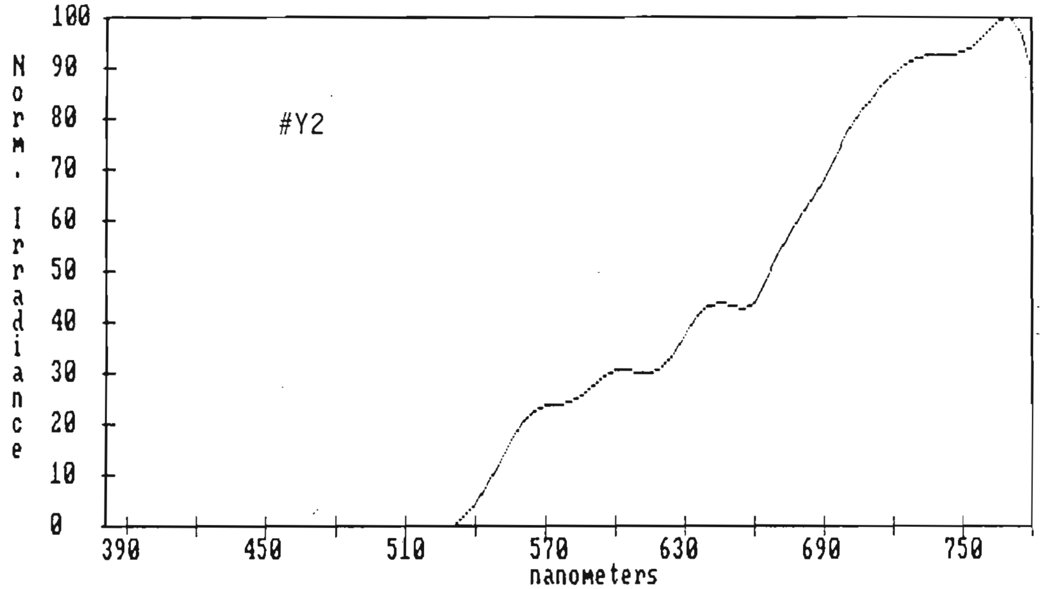
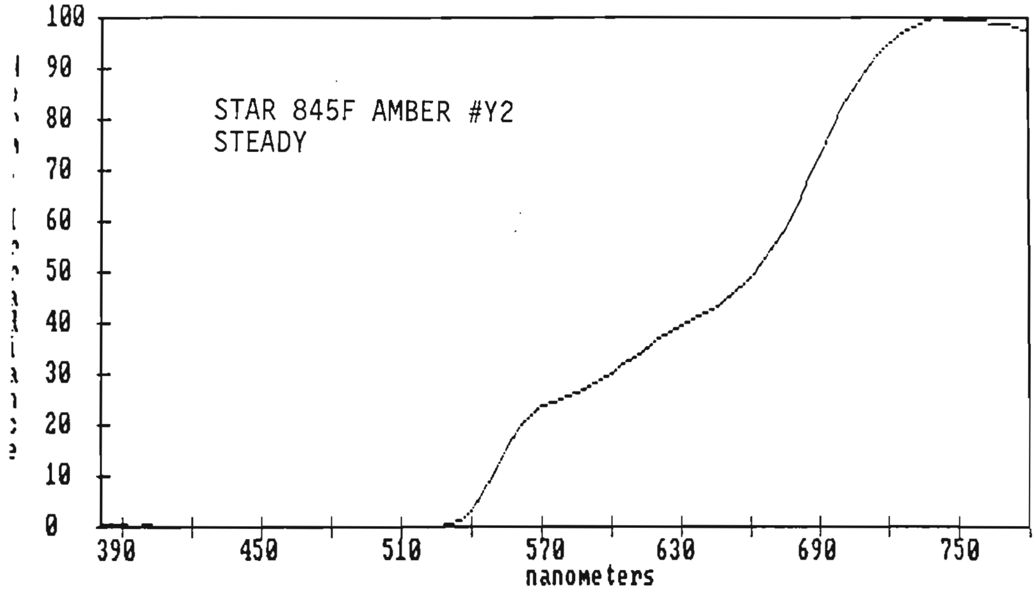


FIGURE A-4. SPECTRAL RESPONSE OF STAR MARKER DEVICES, AMBER LENSE



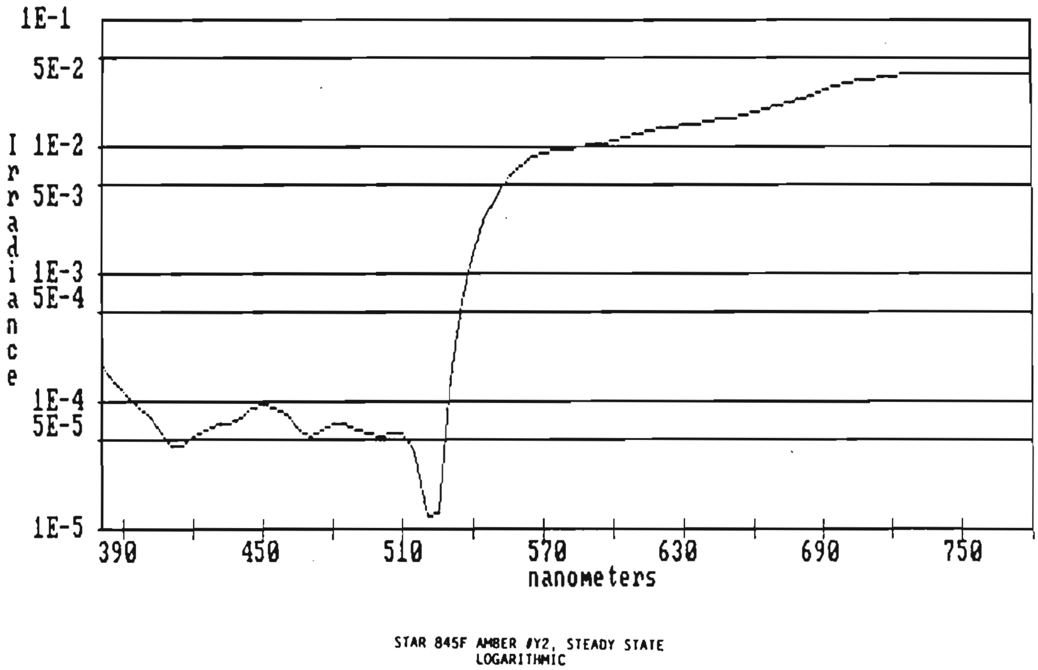
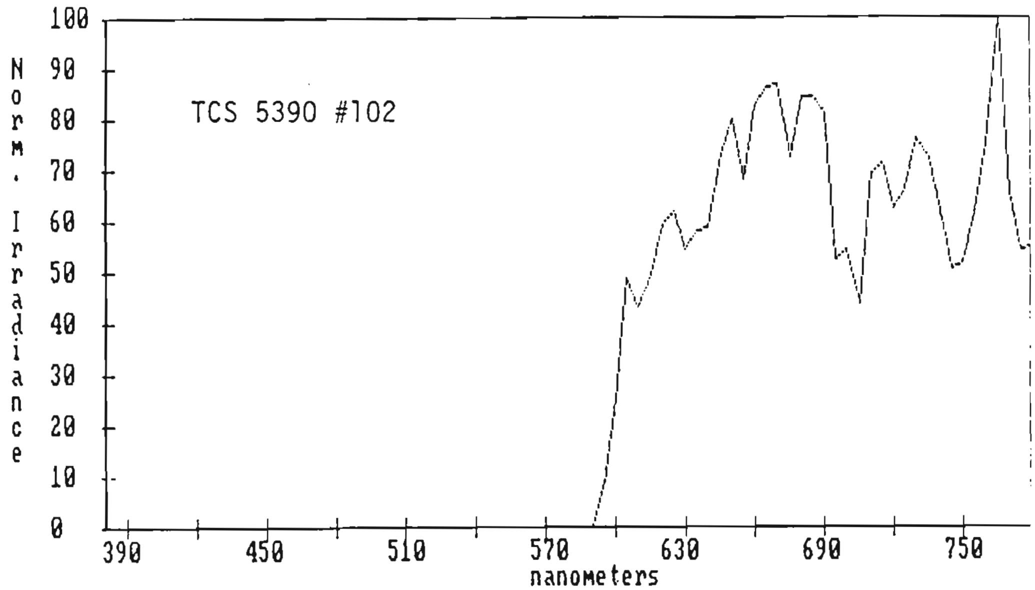


FIGURE A-4. (continued)



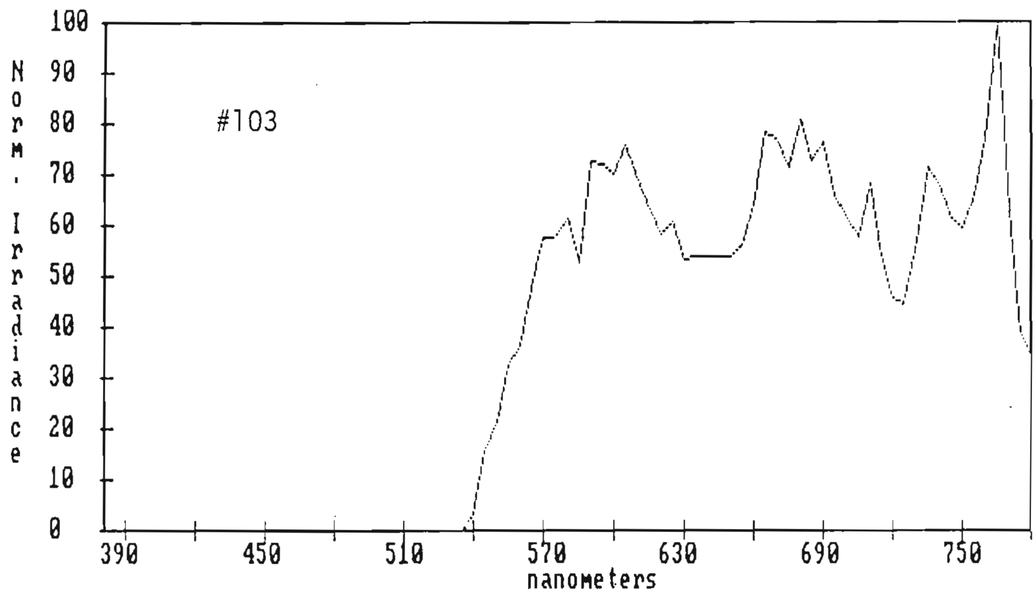
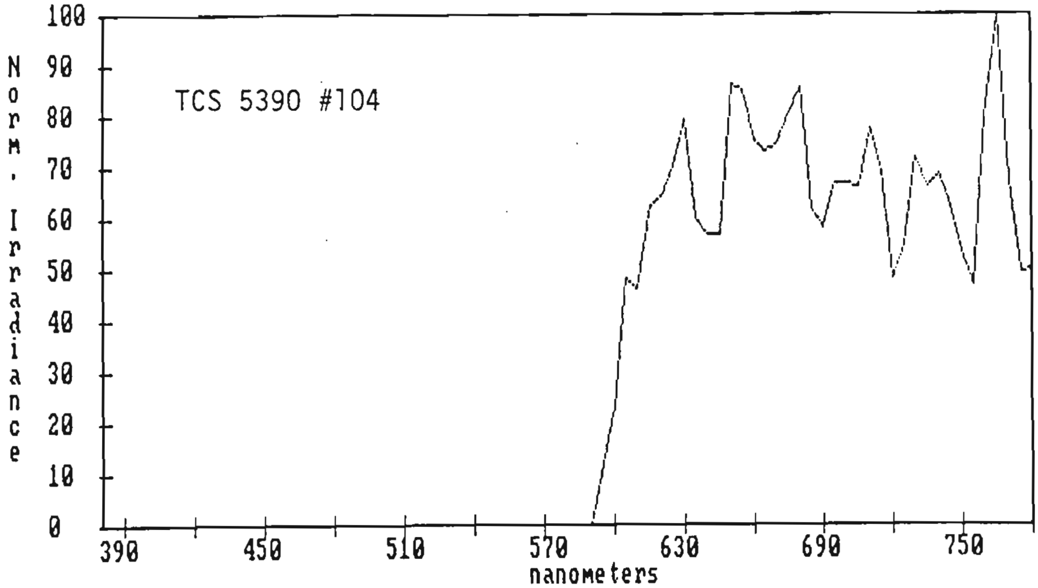


FIGURE A-5. SPECTRAL RESPONSE OF TCS REAR-END MARKER DEVICES



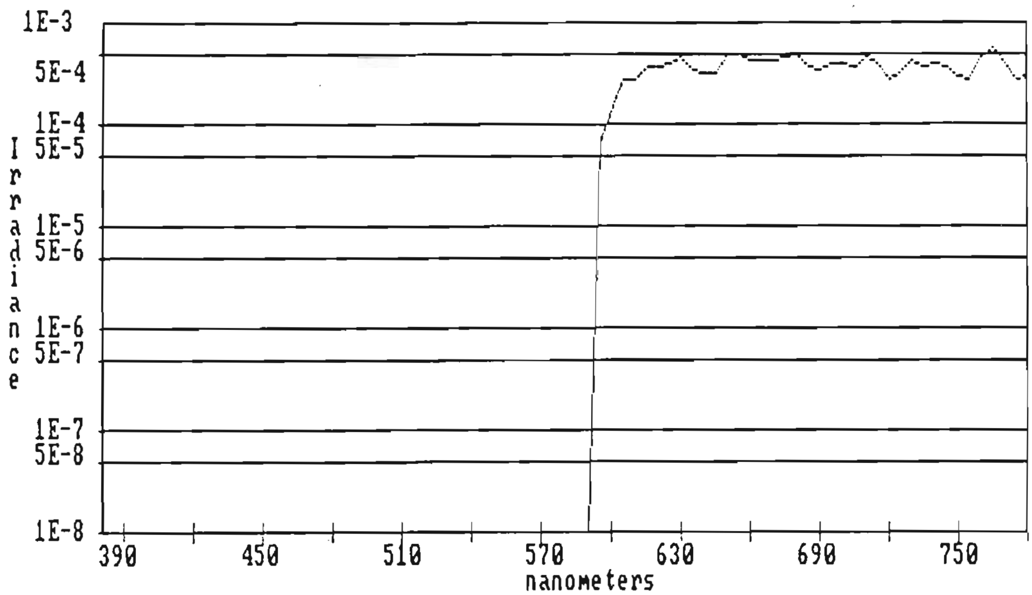
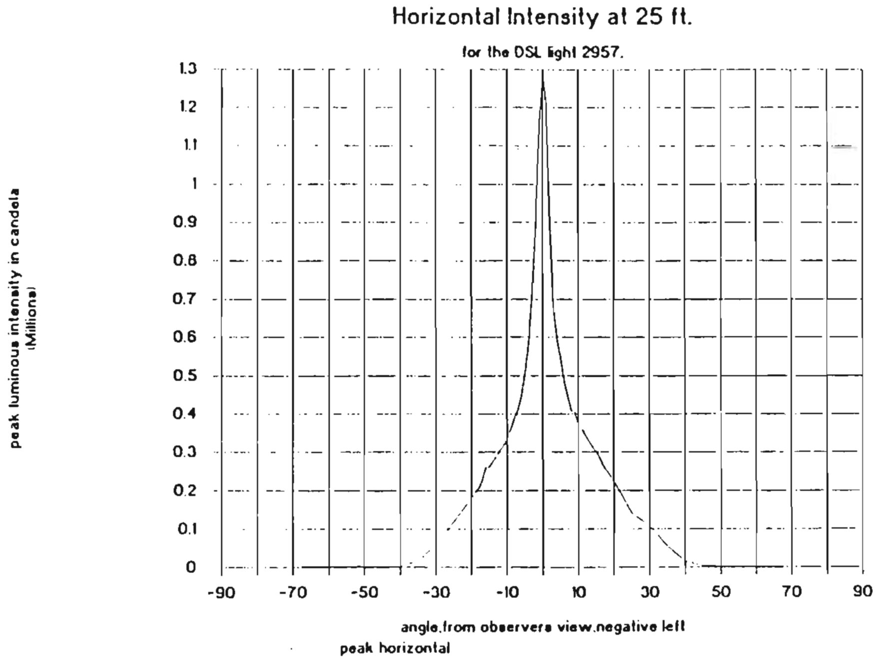


FIGURE A-5. (continued)

APPENDIX B

ANGULAR INTENSITY DATA AT 25 FEET



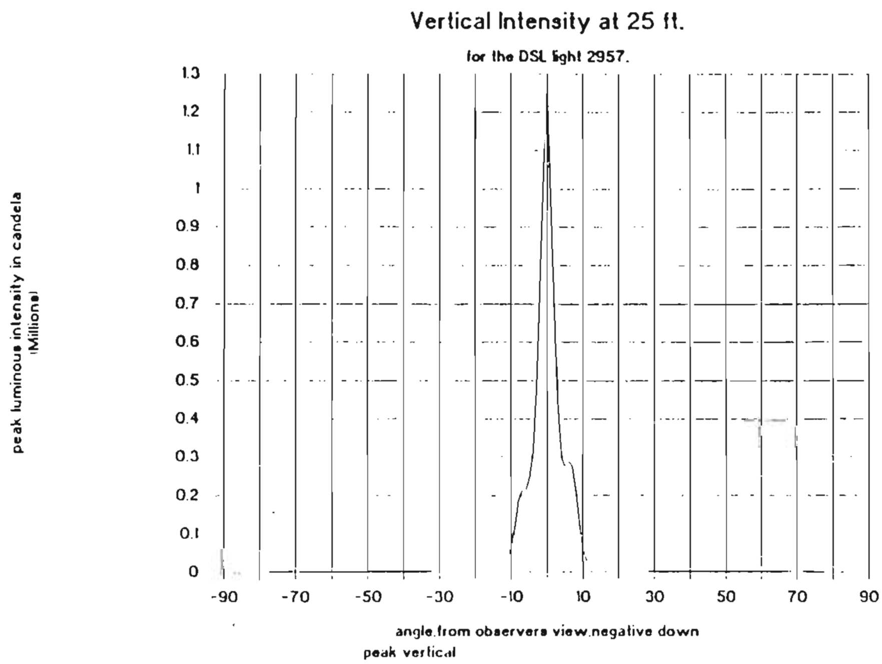
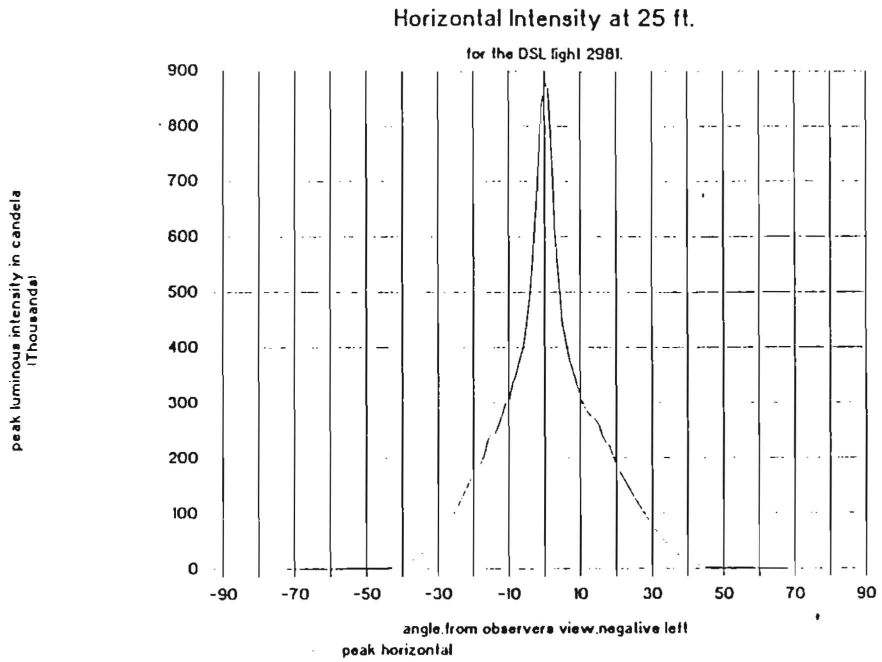


FIGURE B-1. ANGULAR INTENSITY AT 25 FEET, DSL #2957



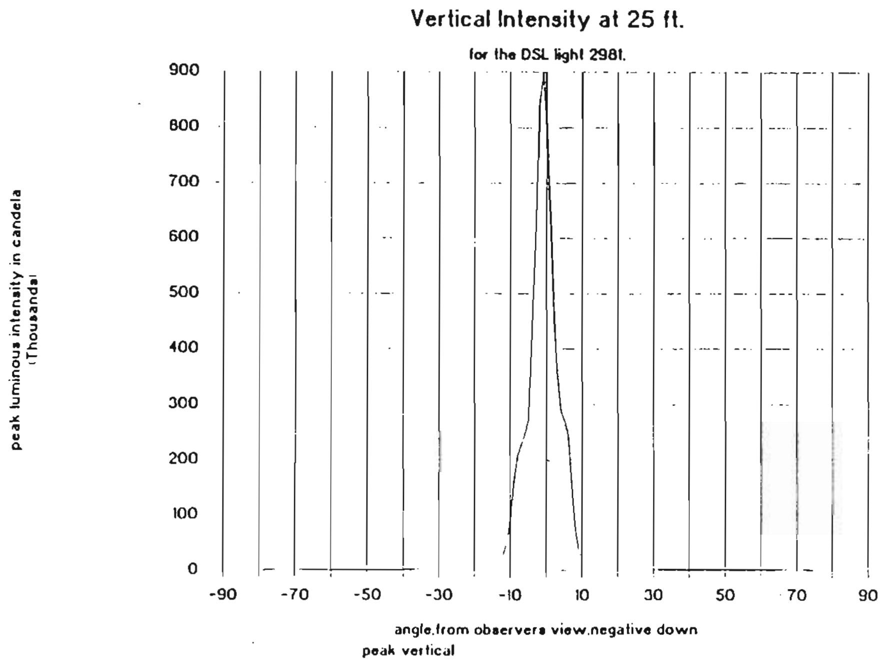
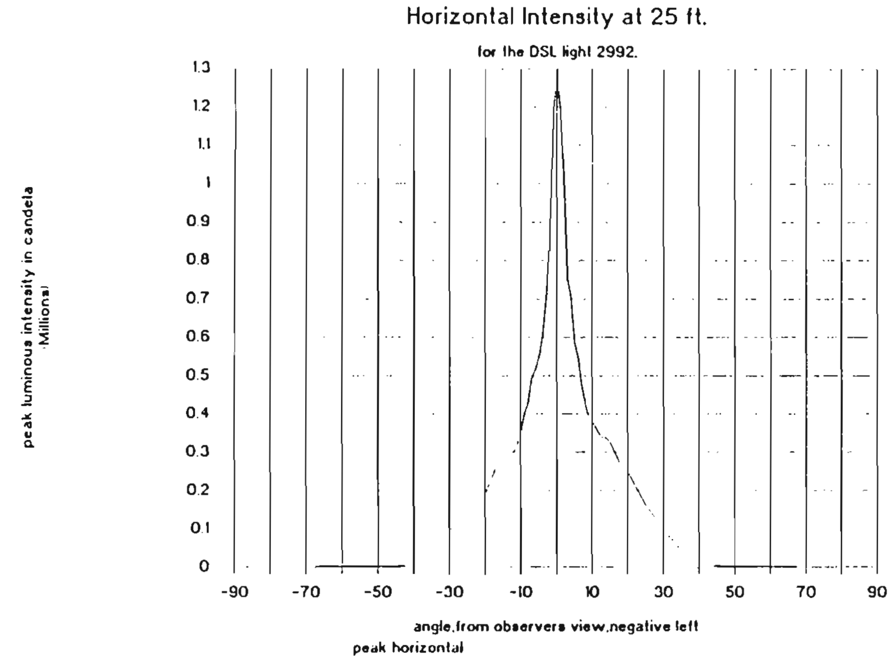


FIGURE B-2. ANGULAR INTENSITY AT 25 FEET, DSL #2981



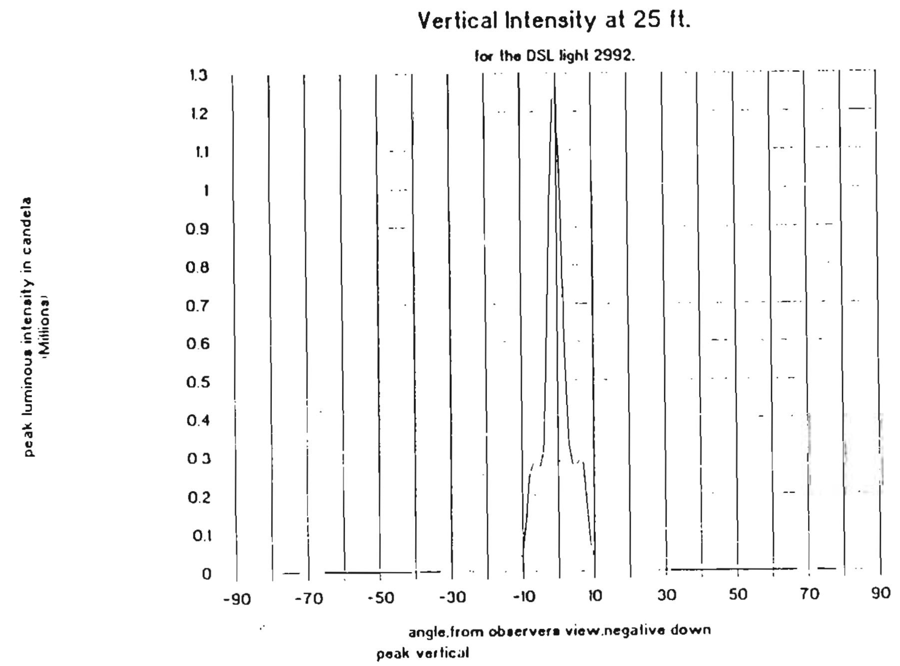
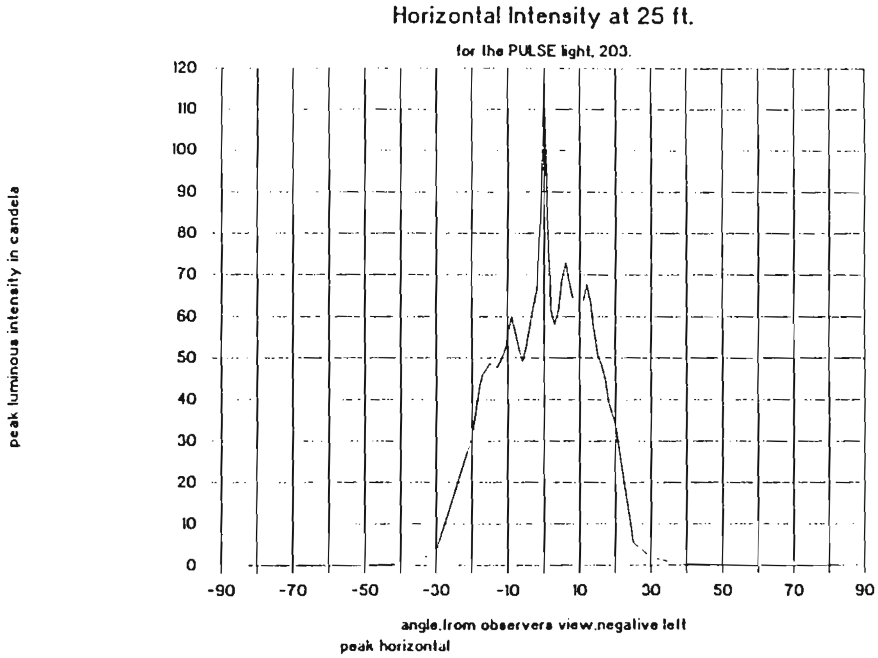


FIGURE B-3. ANGULAR INTENSITY AT 25 FEET, DSL #2992



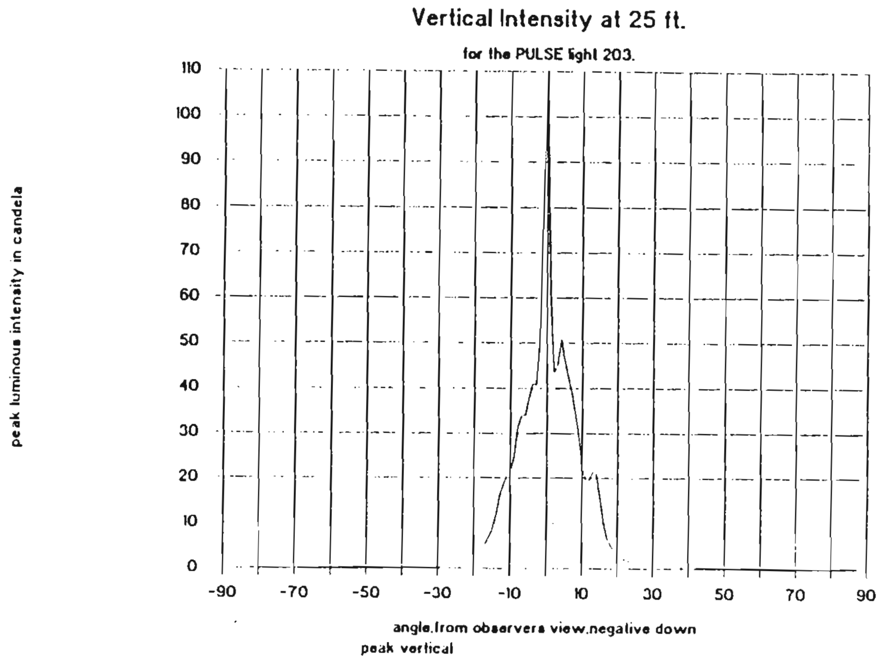
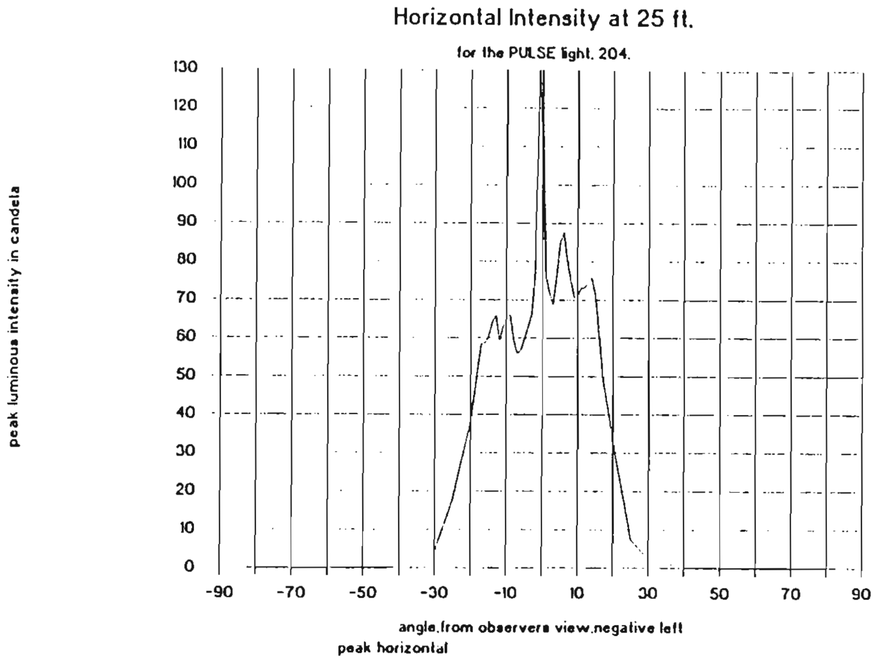


FIGURE B-4. ANGULAR INTENSITY AT 25 FEET, PULSE #203



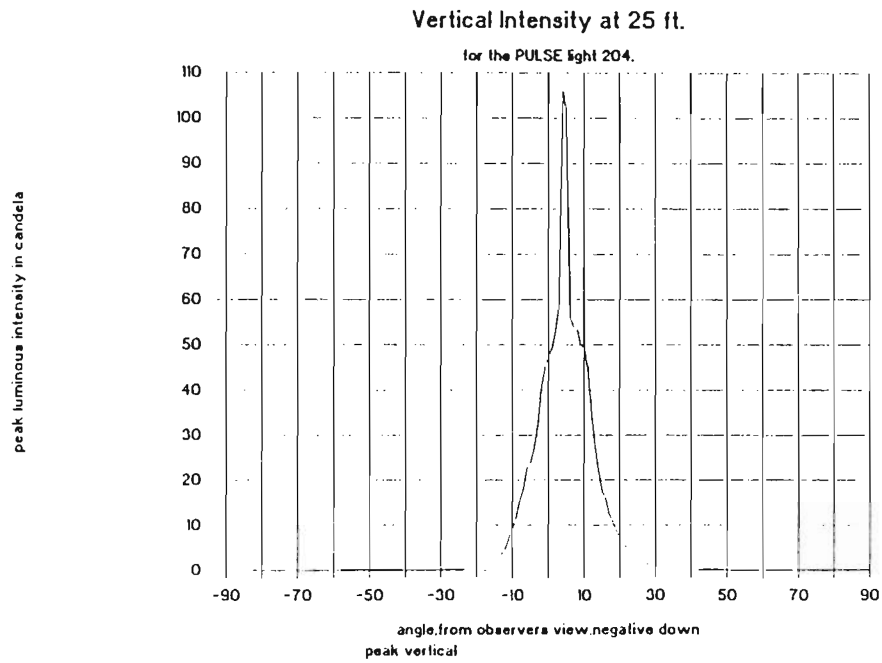
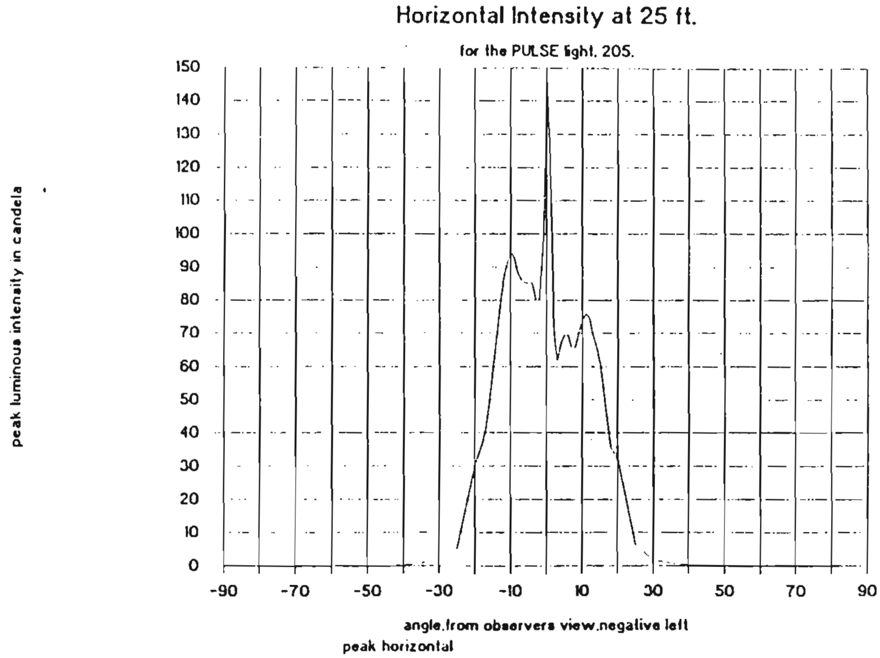


FIGURE B-5. ANGULAR INTENSITY AT 25 FEET, PULSE #204



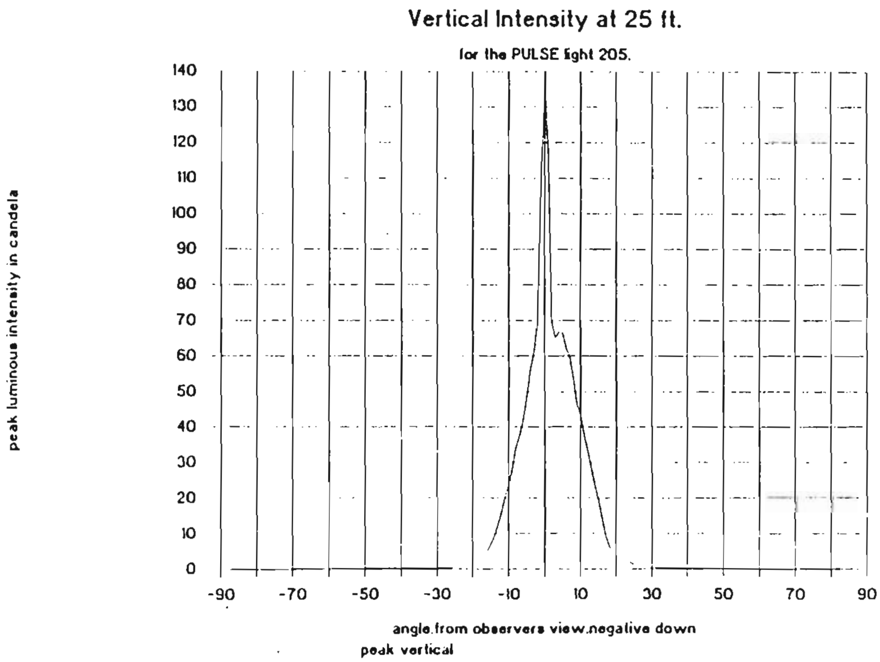
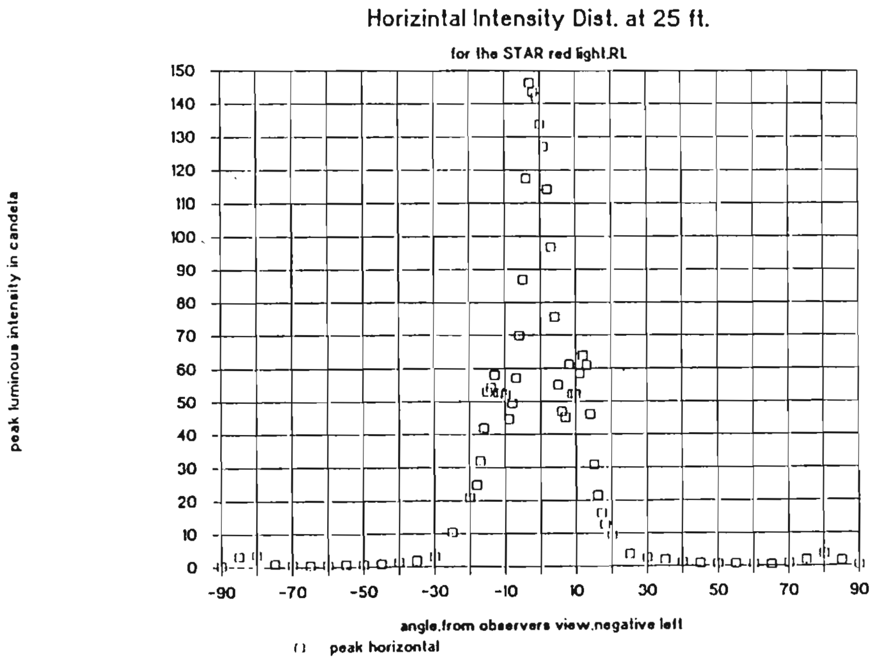


FIGURE B-6. ANGULAR INTENSITY AT 25 FEET, PULSE #205



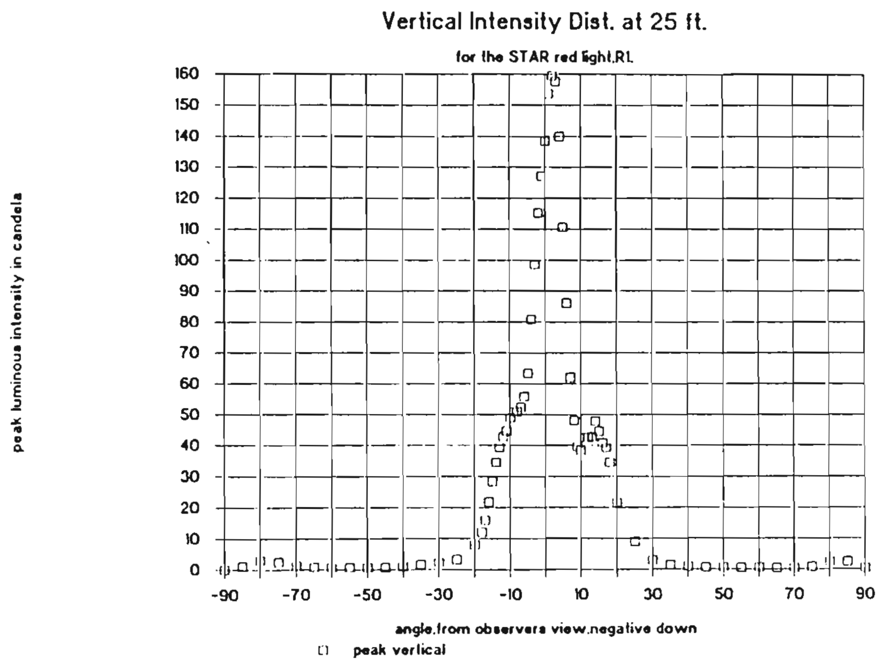
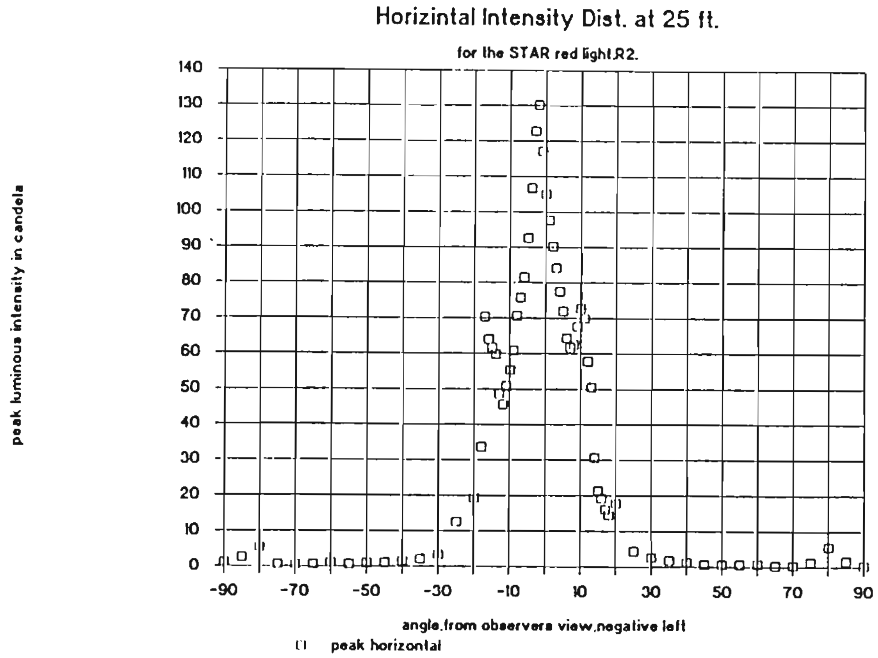


FIGURE B-7. ANGULAR INTENSITY AT 25 FEET, STAR RED LIGHT R1



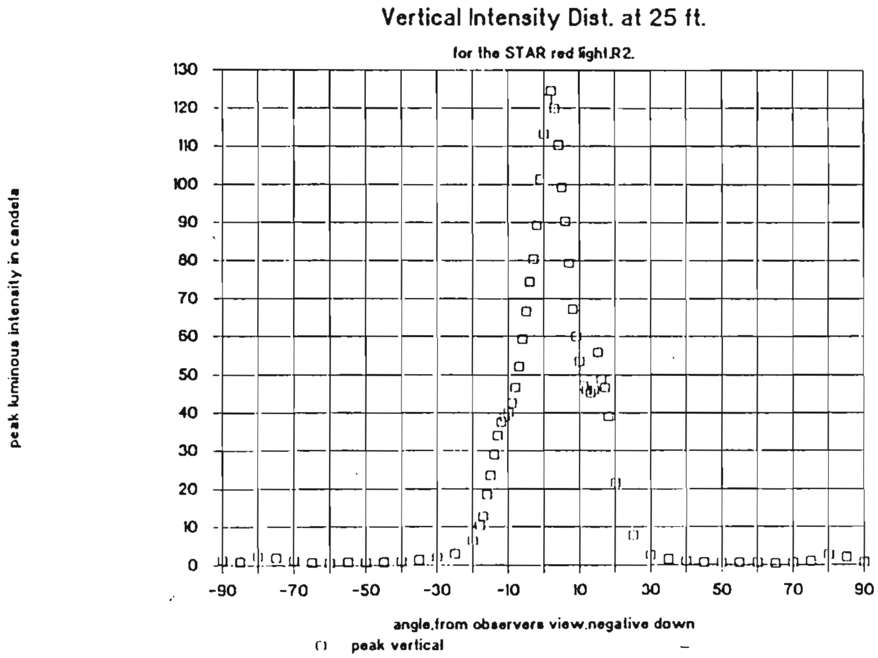
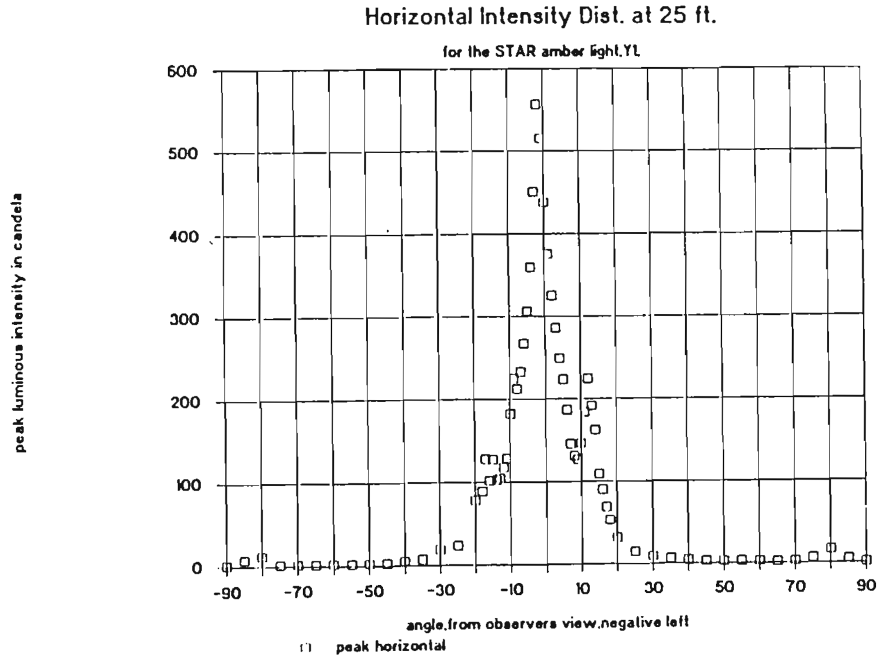


FIGURE B-8. ANGULAR INTENSITY AT 25 FEET, STAR RED LIGHT R2



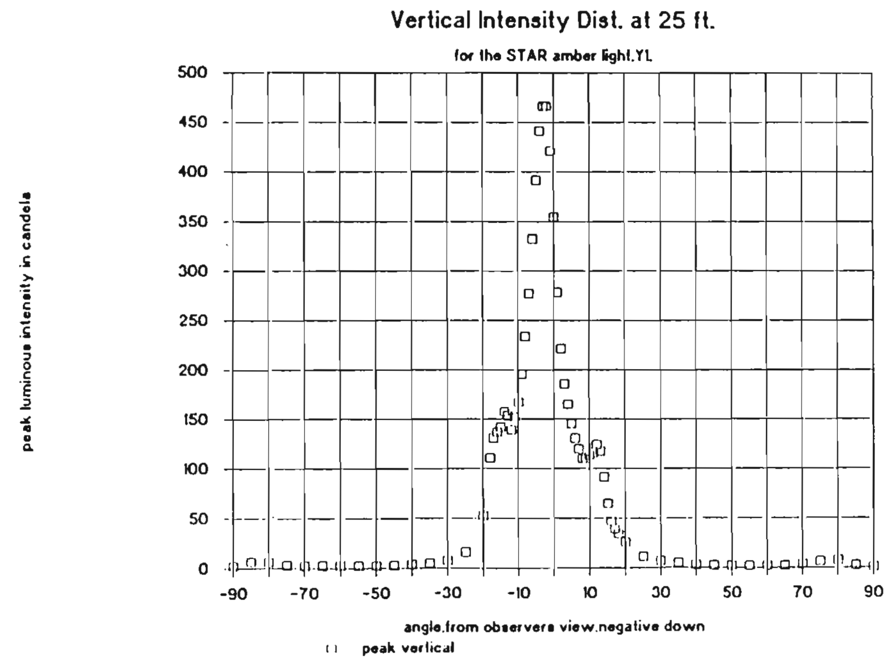
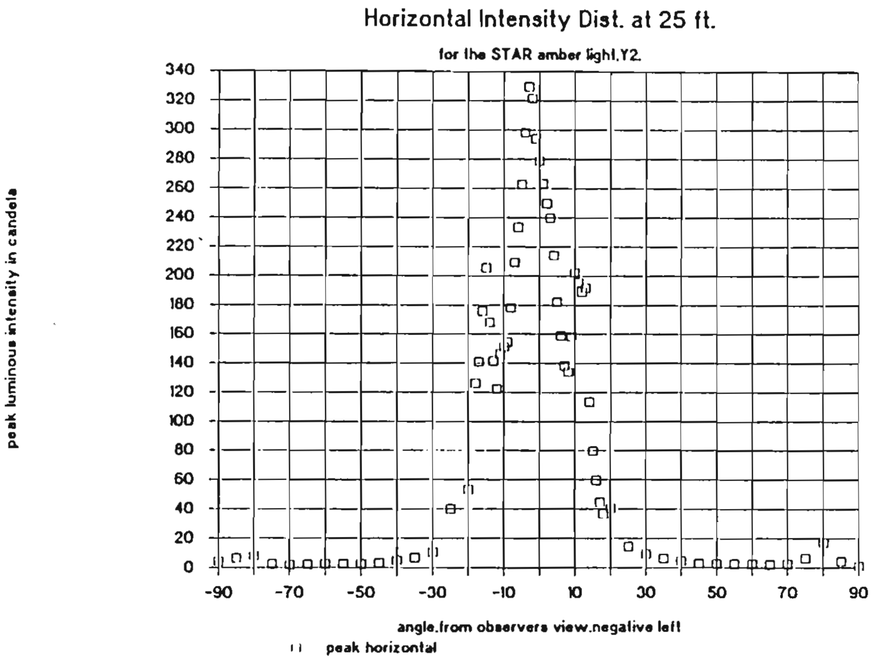


FIGURE B-9. ANGULAR INTENSITY AT 25 FEET, STAR AMBER LIGHT Y1



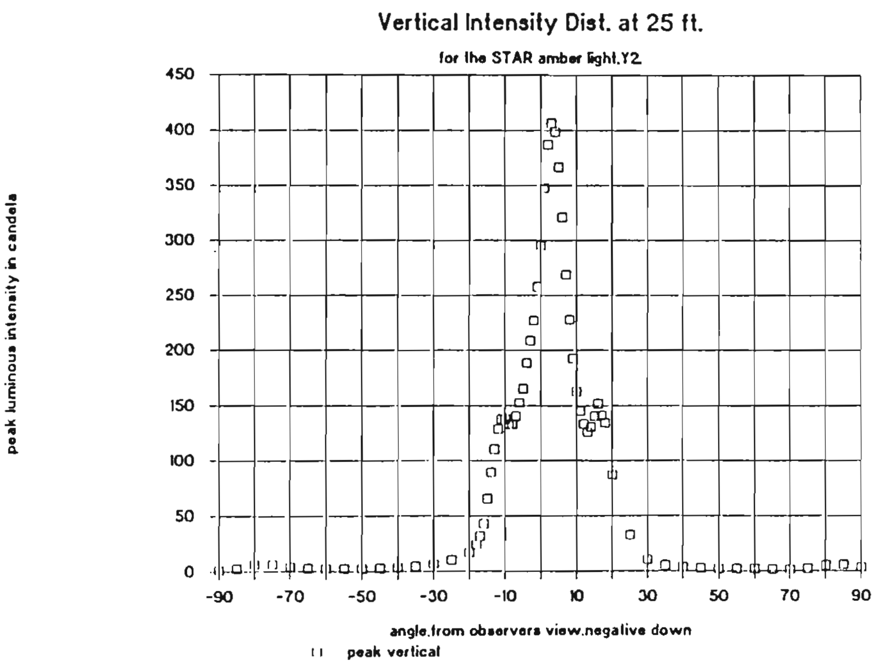
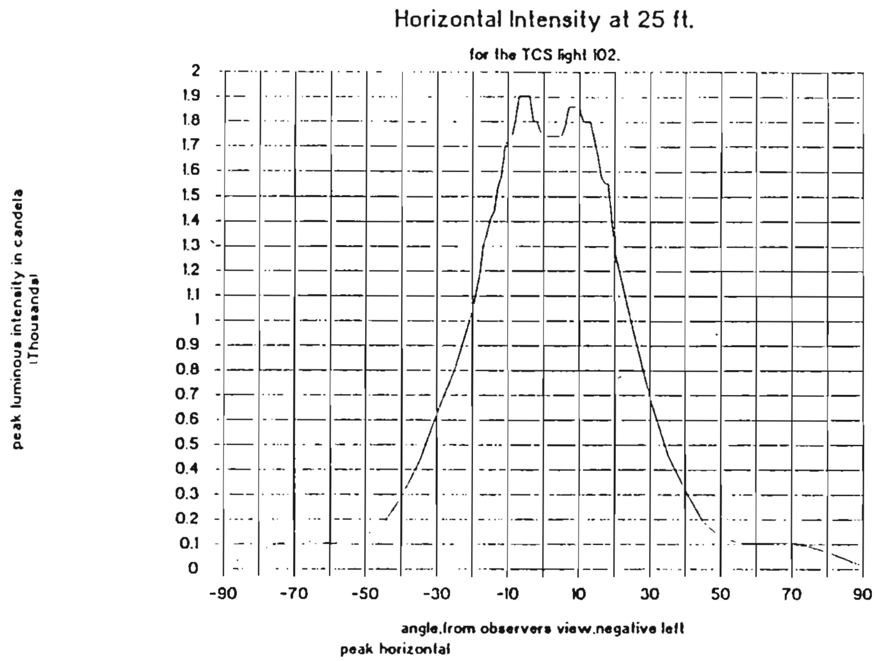


FIGURE B-10. ANGULAR INTENSITY AT 25 FEET, STAR AMBER LIGHT Y2



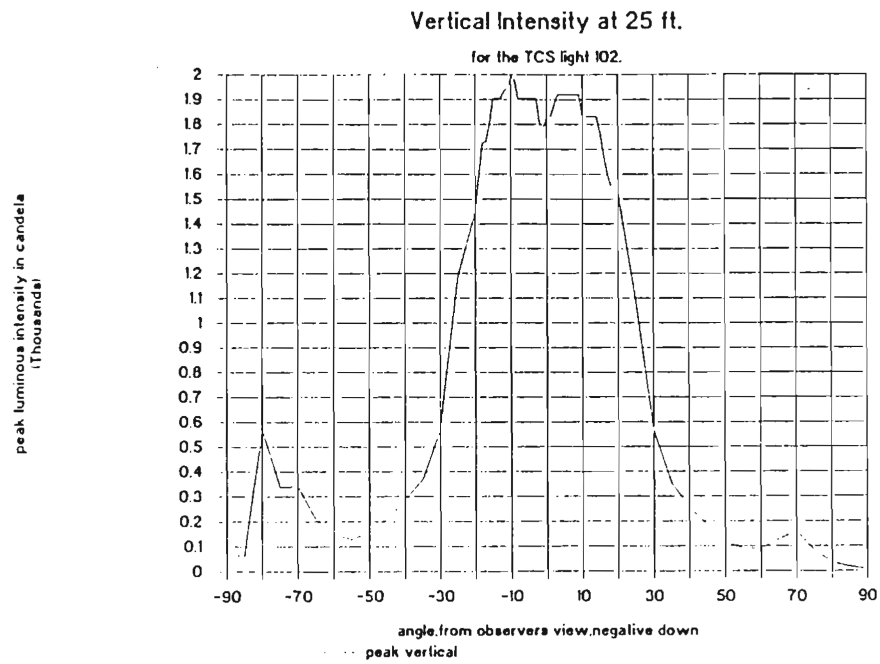
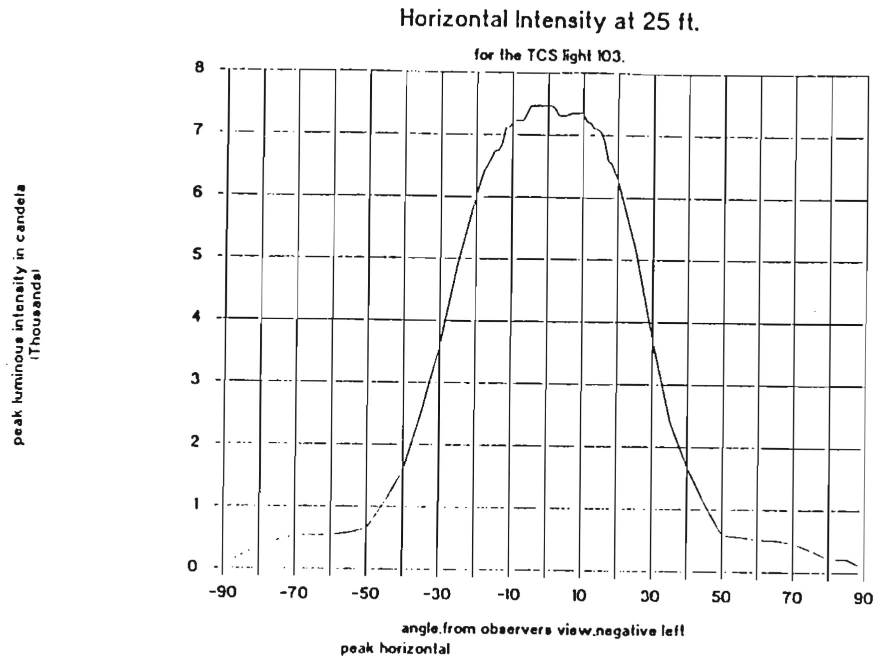


FIGURE B-11. ANGULAR INTENSITY AT 25 FEET, TCS #102



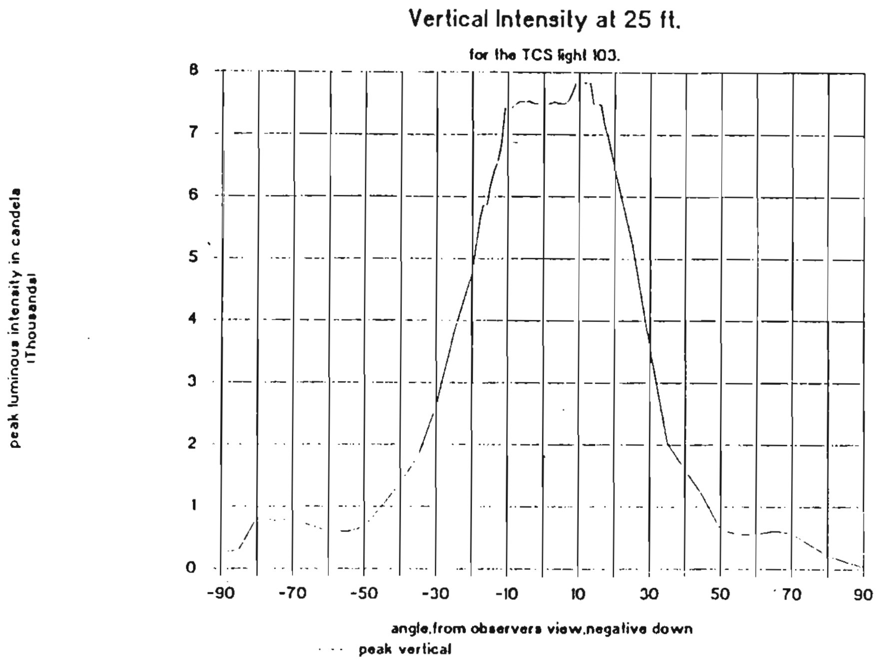
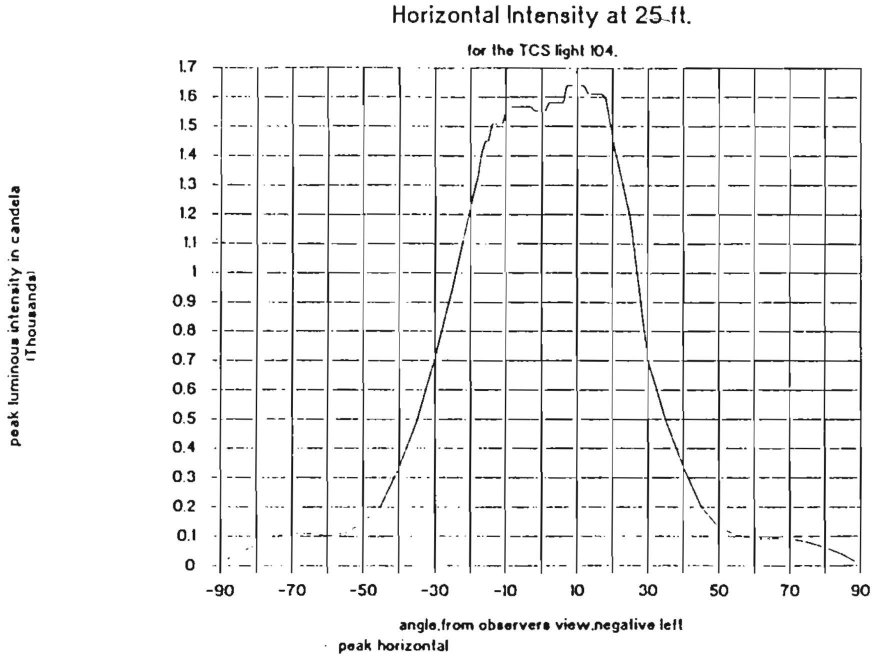


FIGURE B-12. ANGULAR INTENSITY AT 25 FEET, TCS #103



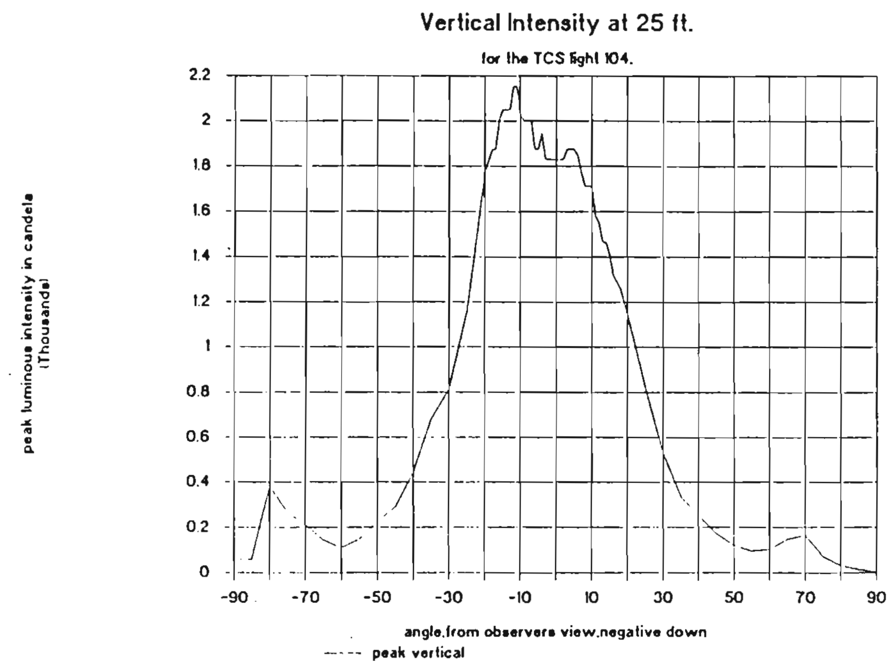
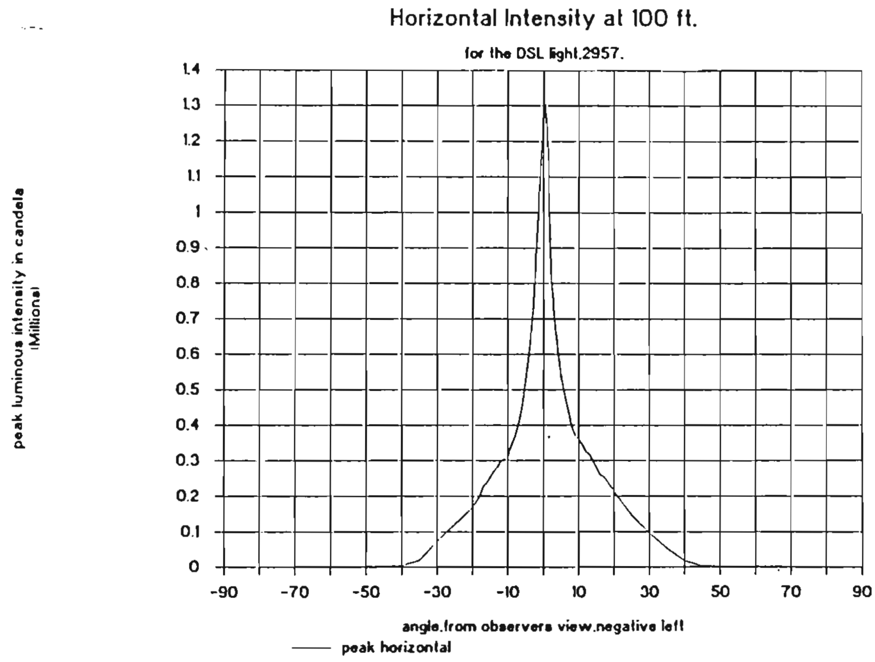


FIGURE B-13. ANGULAR INTENSITY AT 25 FEET, TCS #104

APPENDIX C

ANGULAR INTENSITY DATA AT 100 FEET



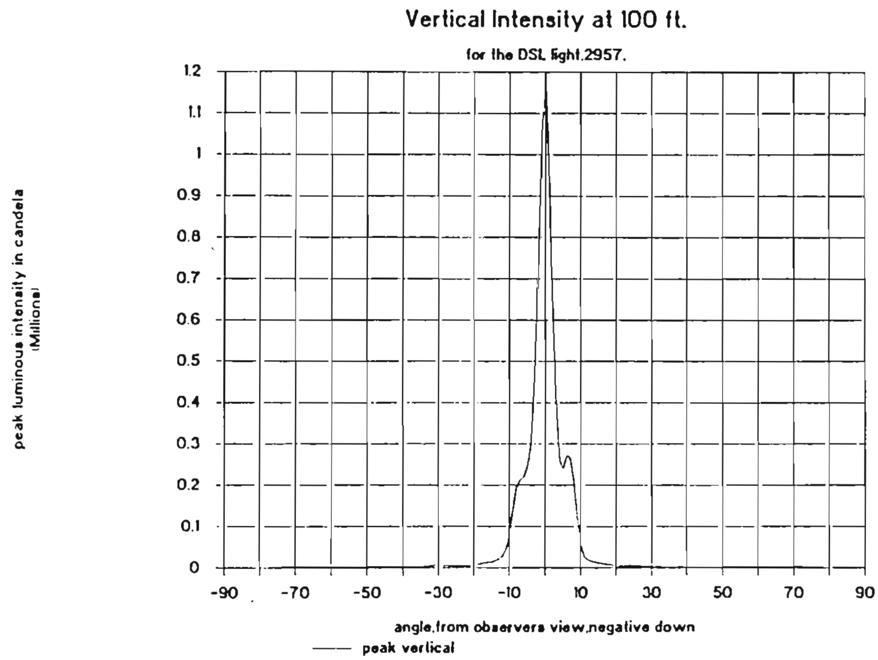
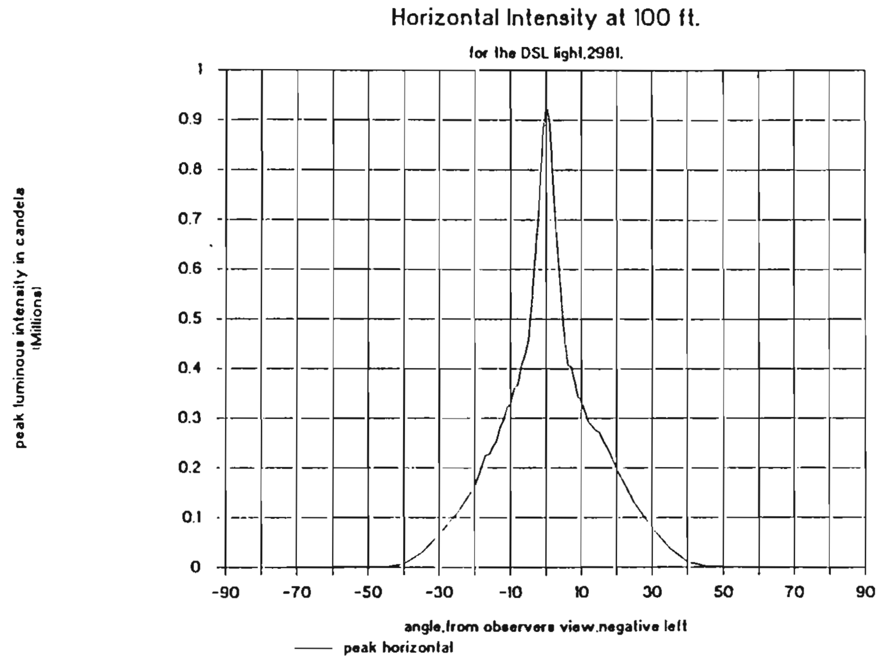


FIGURE C-1. ANGULAR INTENSITY AT 25 FEET, DSL #2957



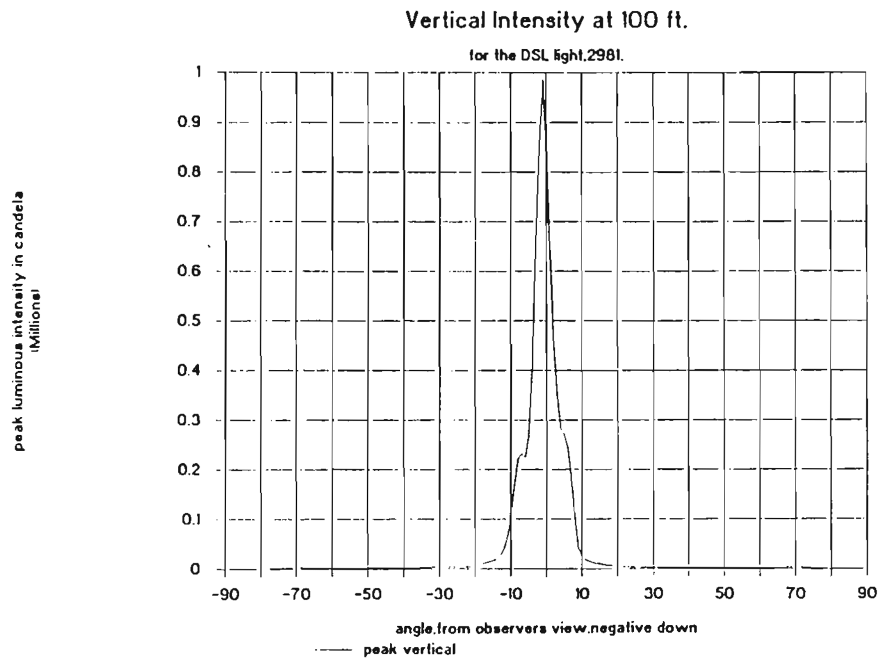
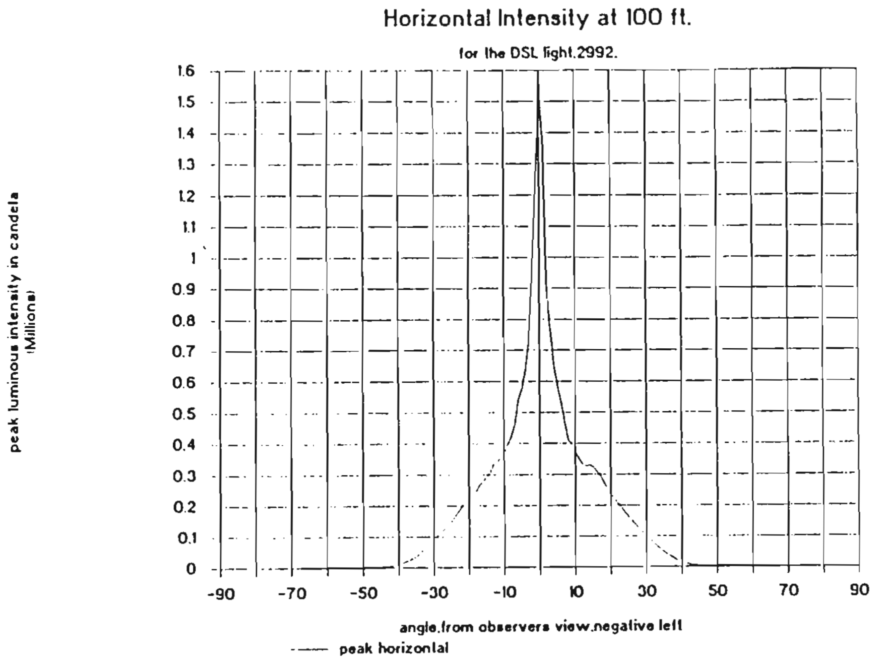


FIGURE C-2. ANGULAR INTENSITY AT 100 FEET, DSL #2981



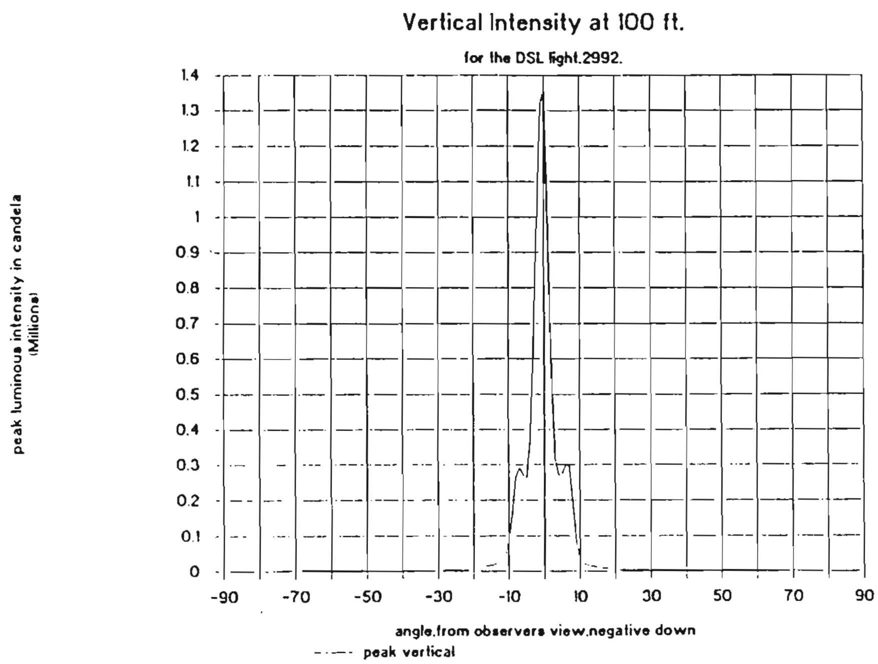
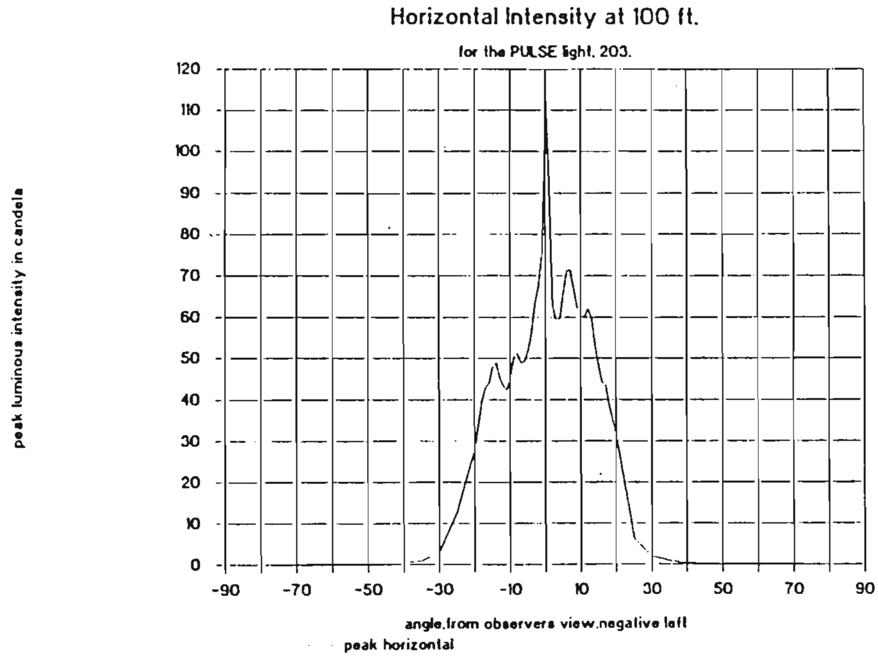


FIGURE C-3. ANGULAR INTENSITY AT 100 FEET, DSL #2992



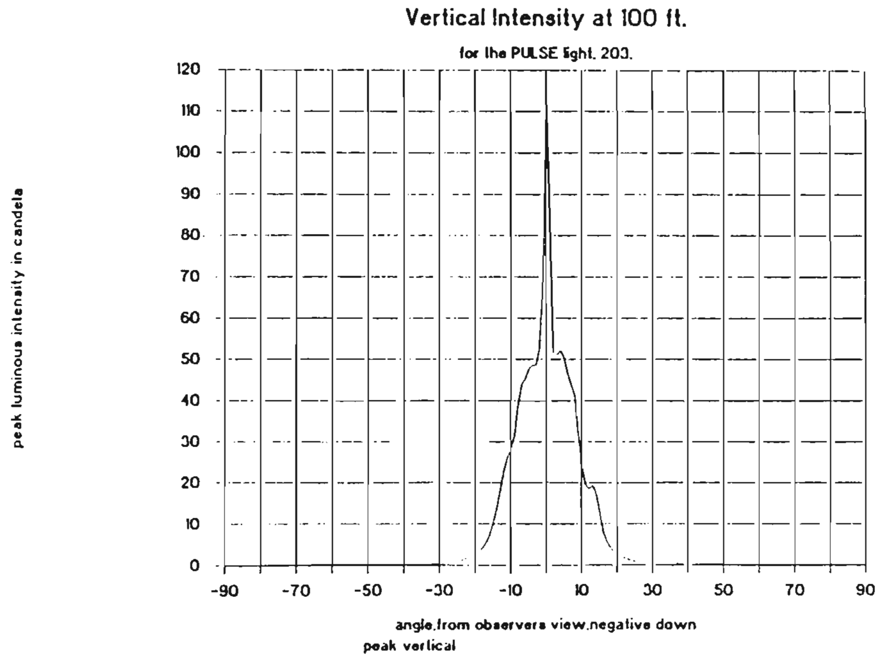
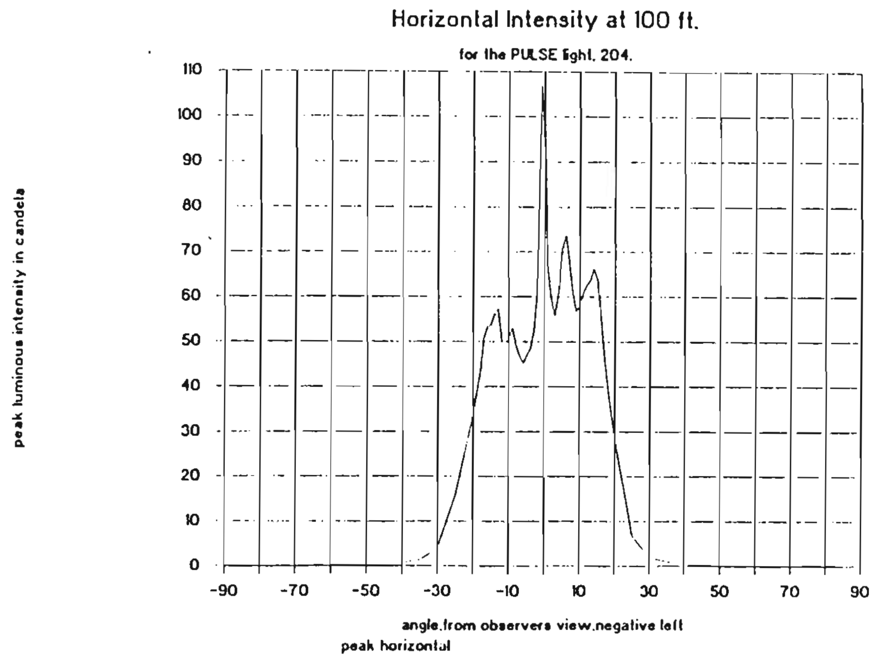


FIGURE C-4. ANGULAR INTENSITY AT 100 FEET, PULSE #203



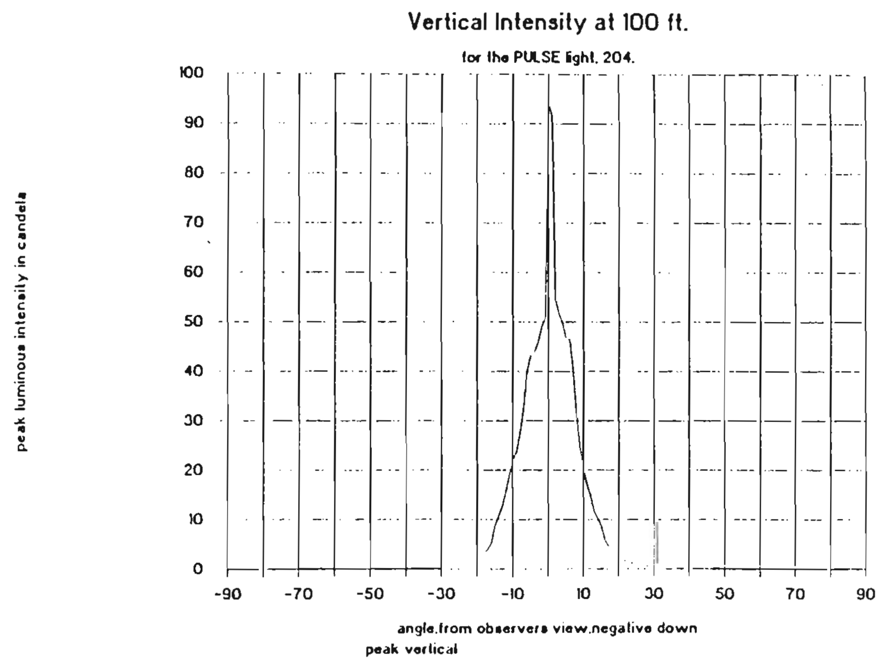
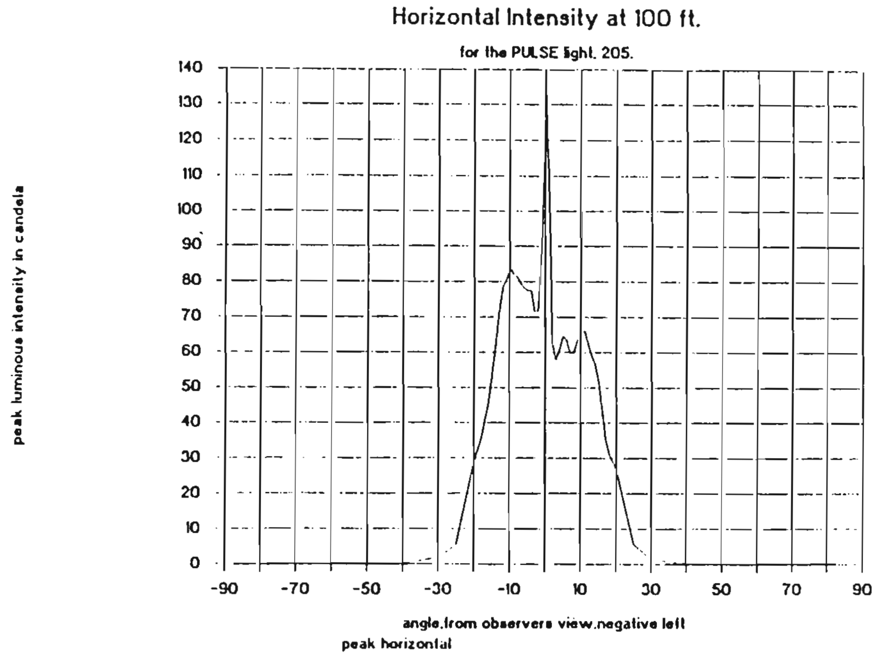


FIGURE C-5. ANGULAR INTENSITY AT 100 FEET, PULSE #204



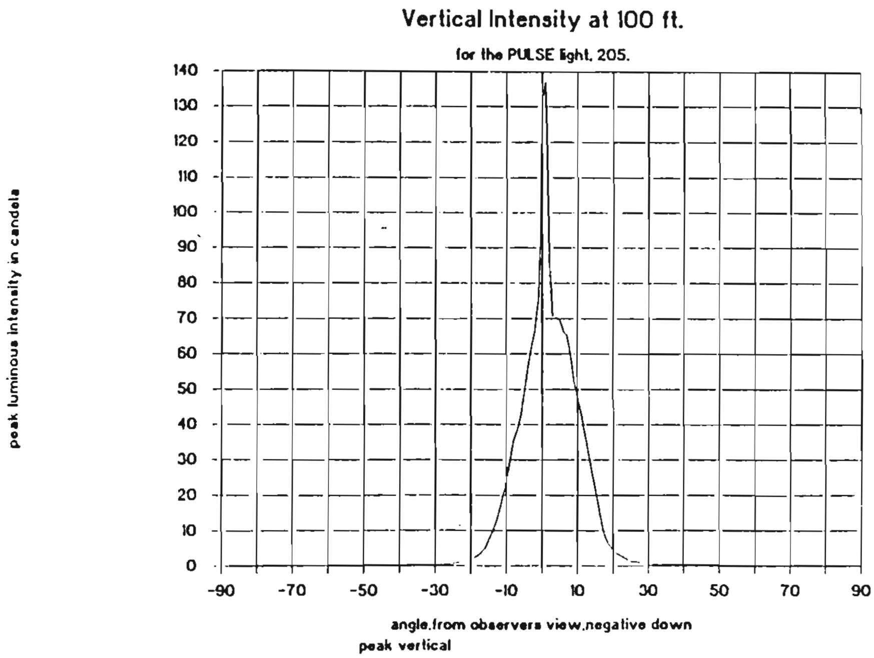
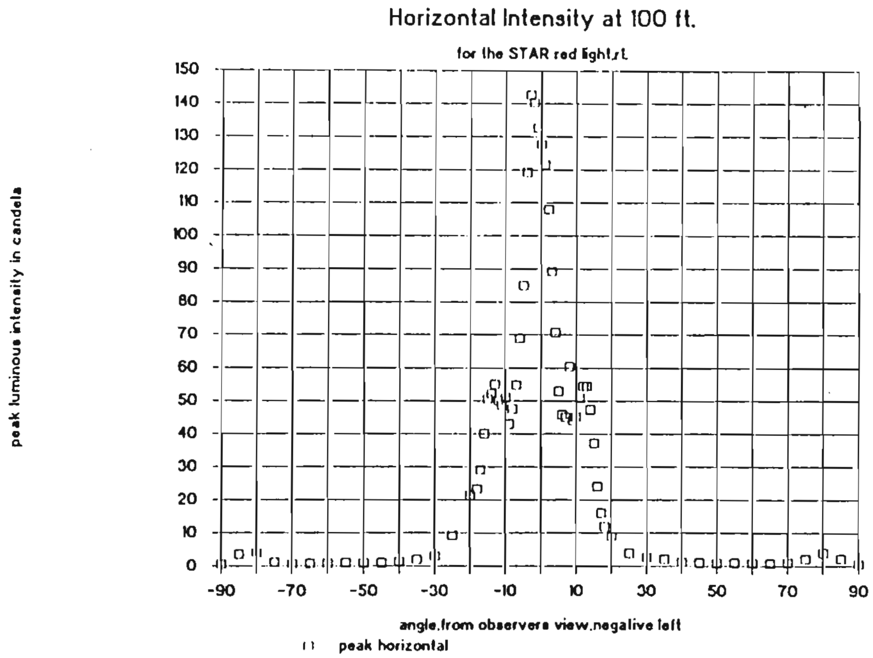


FIGURE C-6. ANGULAR INTENSITY AT 100 FEET, PULSE #205



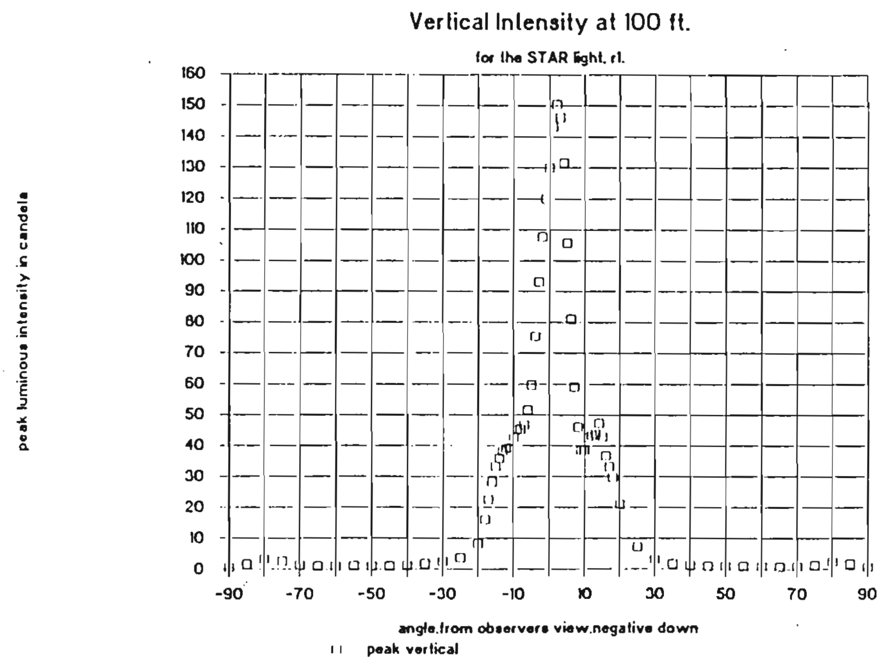
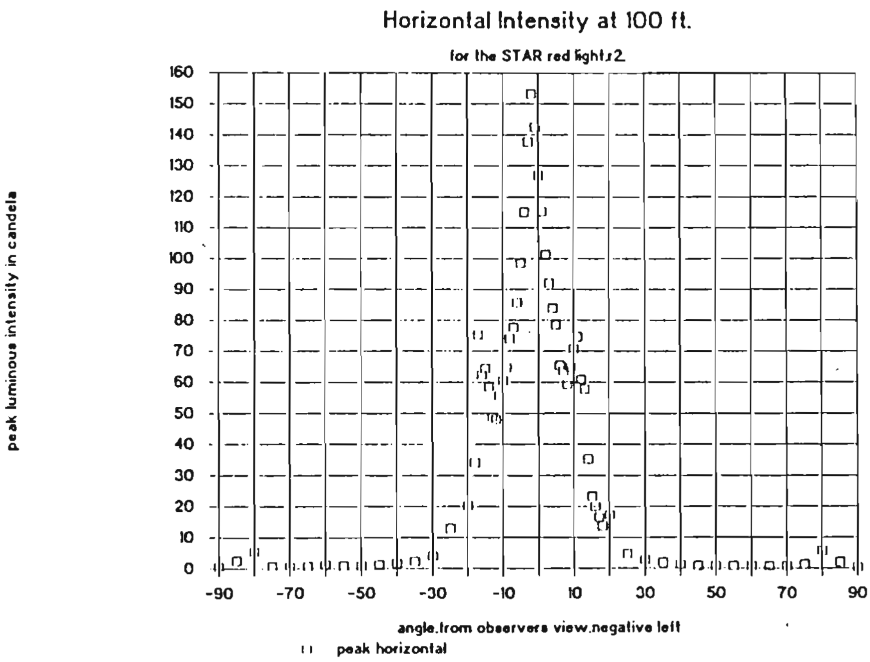


FIGURE C-7. ANGULAR INTENSITY AT 100 FEET, STAR RED LIGHT R1



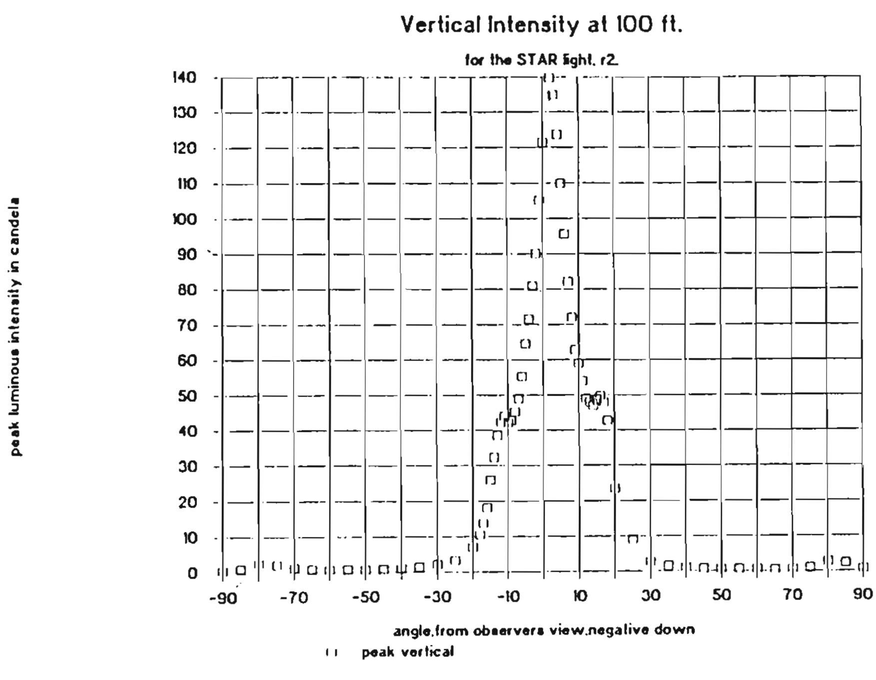
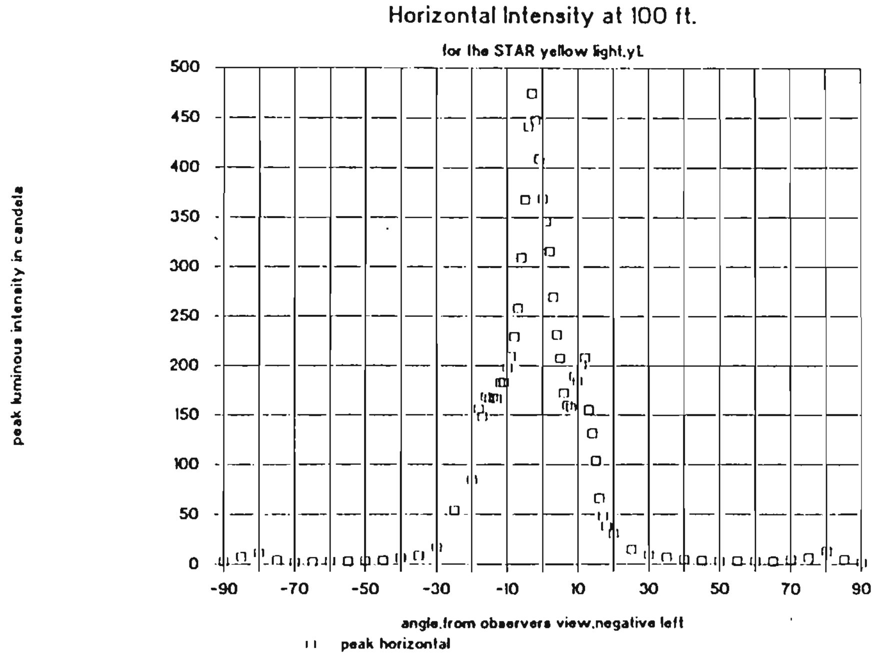


FIGURE C-8. ANGULAR INTENSITY AT 100 FEET, STAR RED LIGHT R2



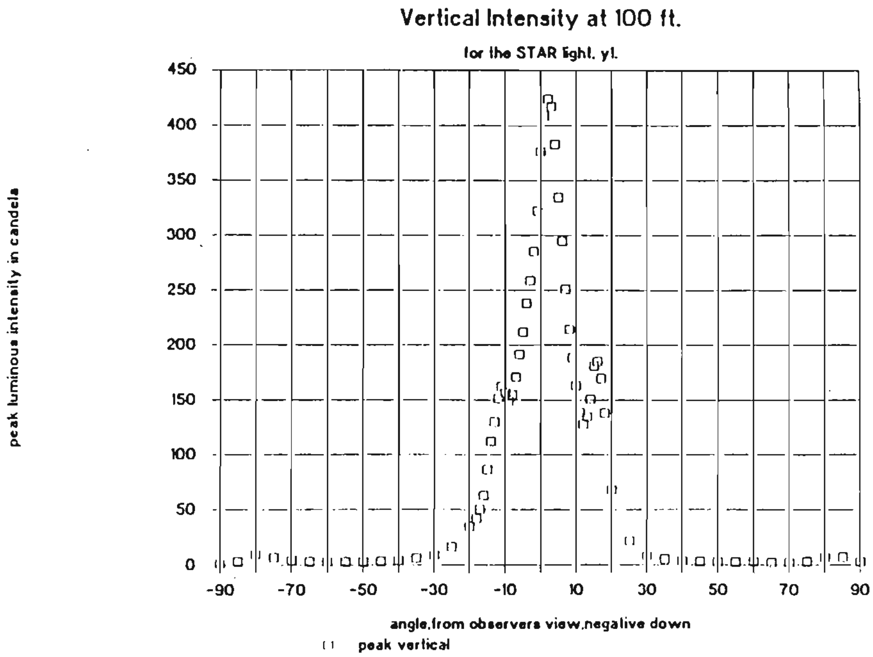
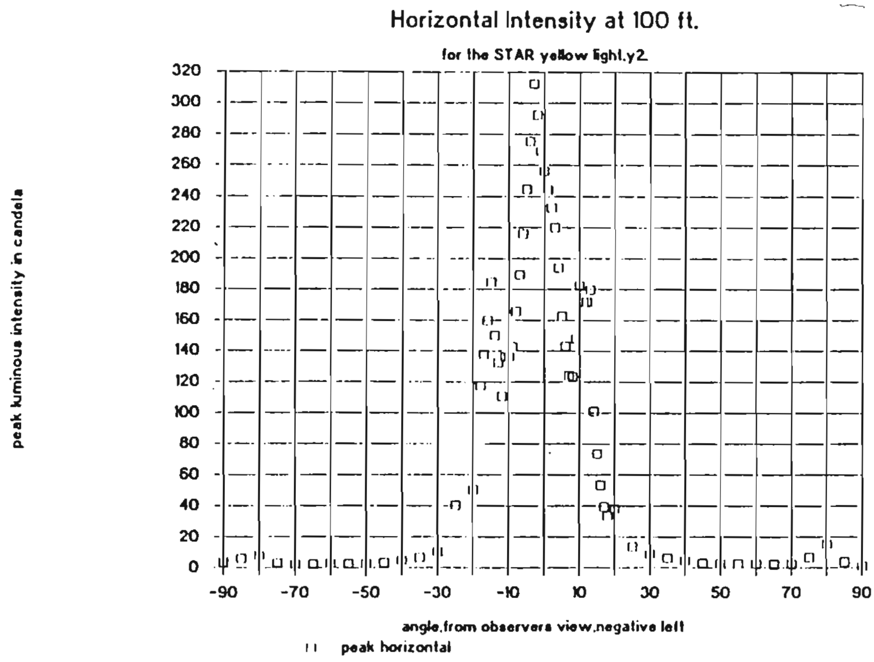


FIGURE C-9. ANGULAR INTENSITY AT 100 FEET, STAR AMBER LIGHT Y1



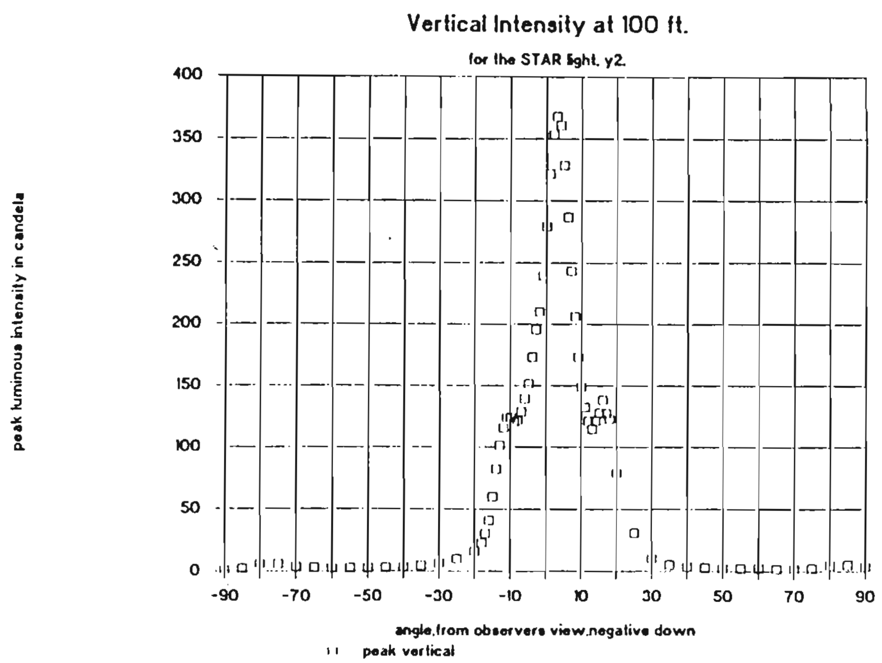
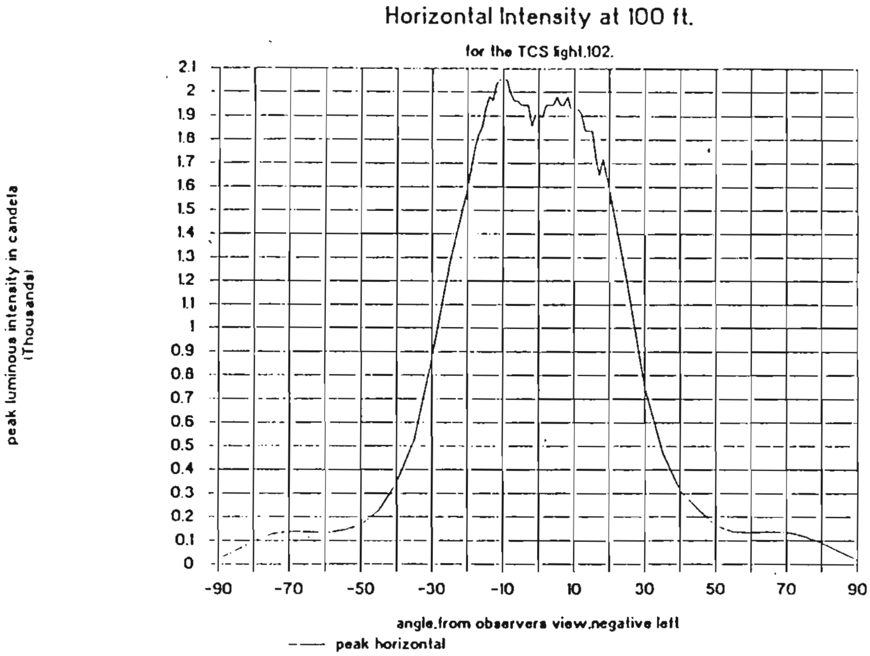


FIGURE C-10. ANGULAR INTENSITY AT 100 FEET, STAR AMBER LIGHT Y2



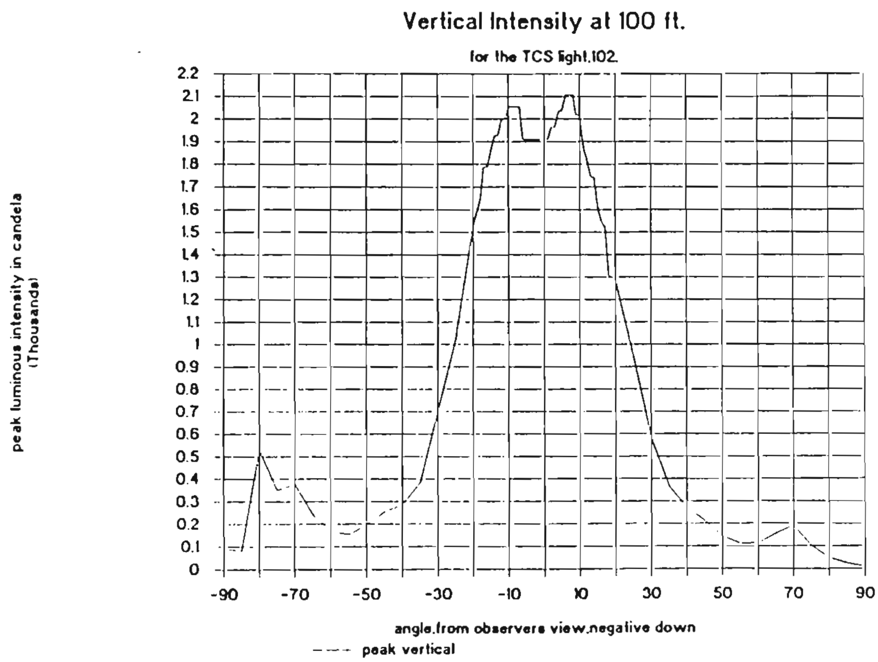
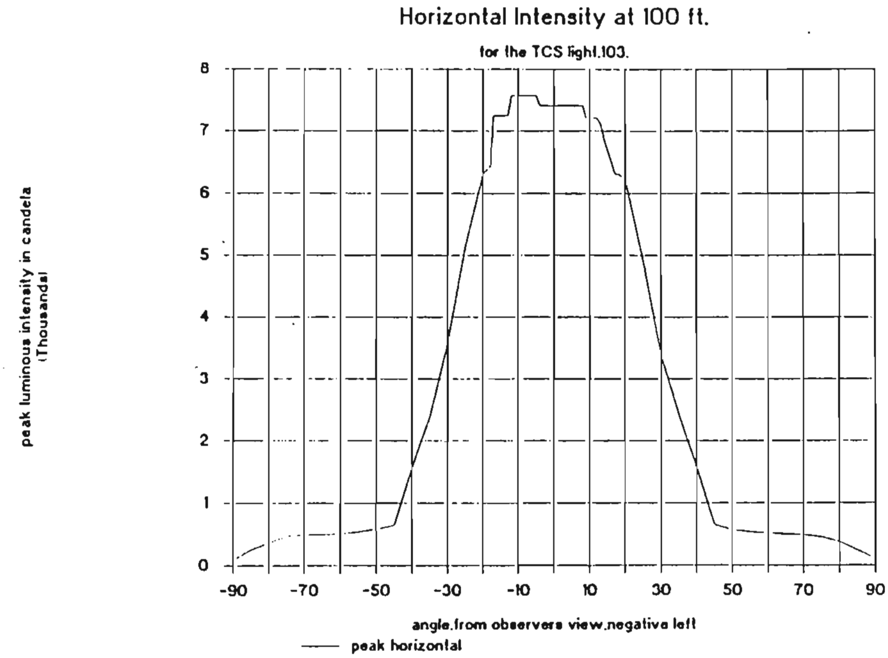


FIGURE C-11. ANGULAR INTENSITY AT 100 FEET, TCS #102



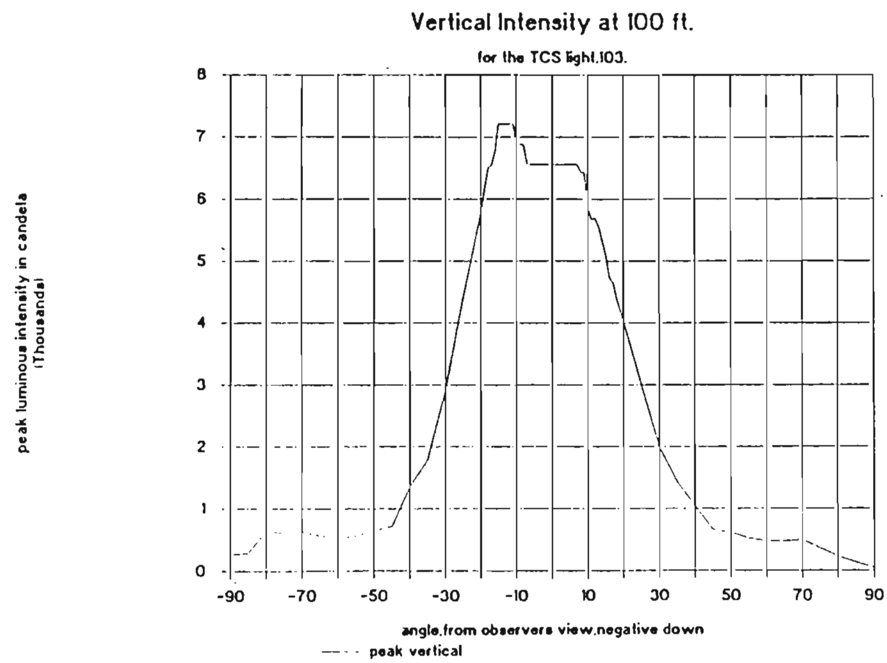
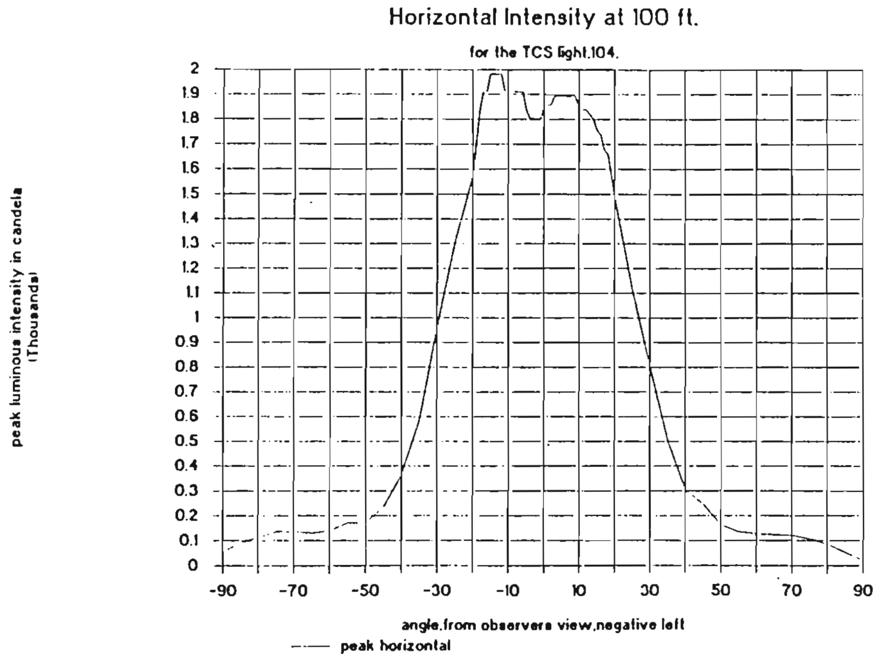


FIGURE C-12. ANGULAR INTENSITY AT 100 FEET, TCS #103



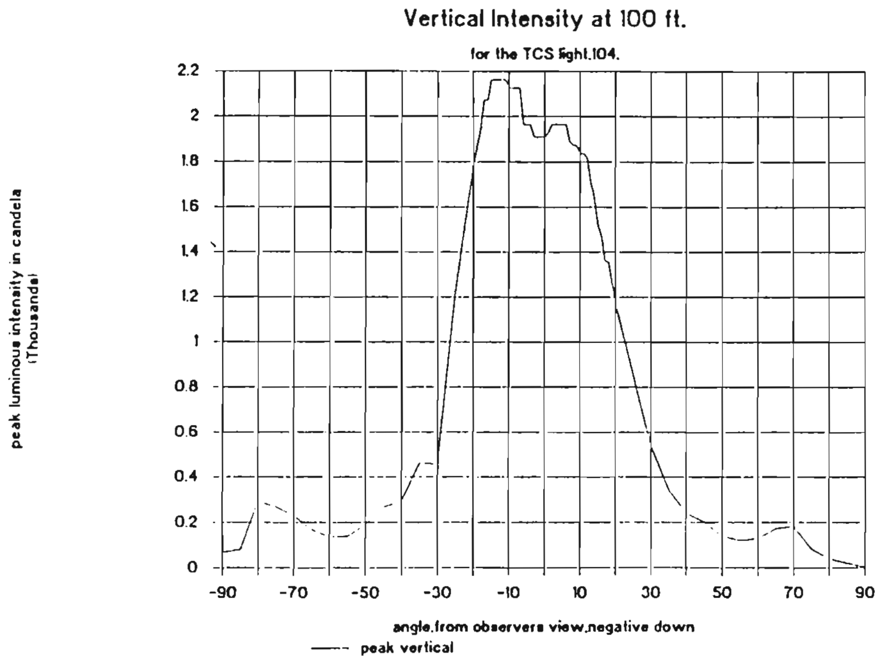


FIGURE C-13. ANGULAR INTENSITY AT 100 FEET, TCS #104

APPENDIX D

MATHEMATICAL DESCRIPTIONS USED IN THE DEVELOPMENT OF THE CURVED APPROACH SIMULATION

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MATHEMATICAL DESCRIPTIONS USED IN THE DEVELOPMENT OF THE CURVED APPROACH SIMULATION

Background

Figure D-1 represents the schematic depiction of a locomotive engineer (Observer) traveling around a bend toward a parked (or slow-moving) train with a rear-end train marker. A 90° viewing angle between the observer's line-of-sight and the marker's emitter line (a line perpendicular to the plane of the marker) is assumed to be the maximum angle worth considering. This is because, beyond 90°, the observer is essentially on the other side of the marked train car and presumably would not see the marker. (Of course, the observer might pick up secondary cues such as light reflections from the ground or other objects).

The Statement of Work (SOW) states that at least 1000' of unobscured line of sight for the observer (O) is required for the test. For convenience, then, this is used as the diameter of the half-circle in Figure D-1. From this the following results are obtained:

Radius = $r = 500'$

Circumference (whole circle) = $C = 2\pi r = 2\pi(500) = 3141.6'$

Circumference (half circle) = $C' = C/2 = 1570.8'$

<u>Degree of track</u>: The FRA defines the degree of track curvature as the angle subtended by a 100' chord joining two points on the curve. Thus, given a curve of, say 12°, one can find the radius as follows (see Figure D-2 for clarification):

a) find $\tan(\theta/2) = (100'/2)/x \implies x = 50'/(\tan(\theta/2))$

so $x = 50'/(\tan 6°) = 475.72'$

b) use the Pythagorean Theorem to find the radius, r:

$$r = [x^2 + y^2]^{\frac{1}{2}} = \{ [50'/\tan(12°/2)]^2 + 50'^2\}^{\frac{1}{2}} = 478.3'.$$

The diameter of a 12° circular track, then, is 2(478.3') or 956.7'. Similarly, given a radius, r, it is straight forward to compute the degree of curvature. The angle, θ, subtended by a 100' chord is given by the following formula:

$$\theta = 2 * \arcsin(50'/r)$$

Thus, if one considers the radius of 500' used in this field test, the degree of track curvature simulated was:

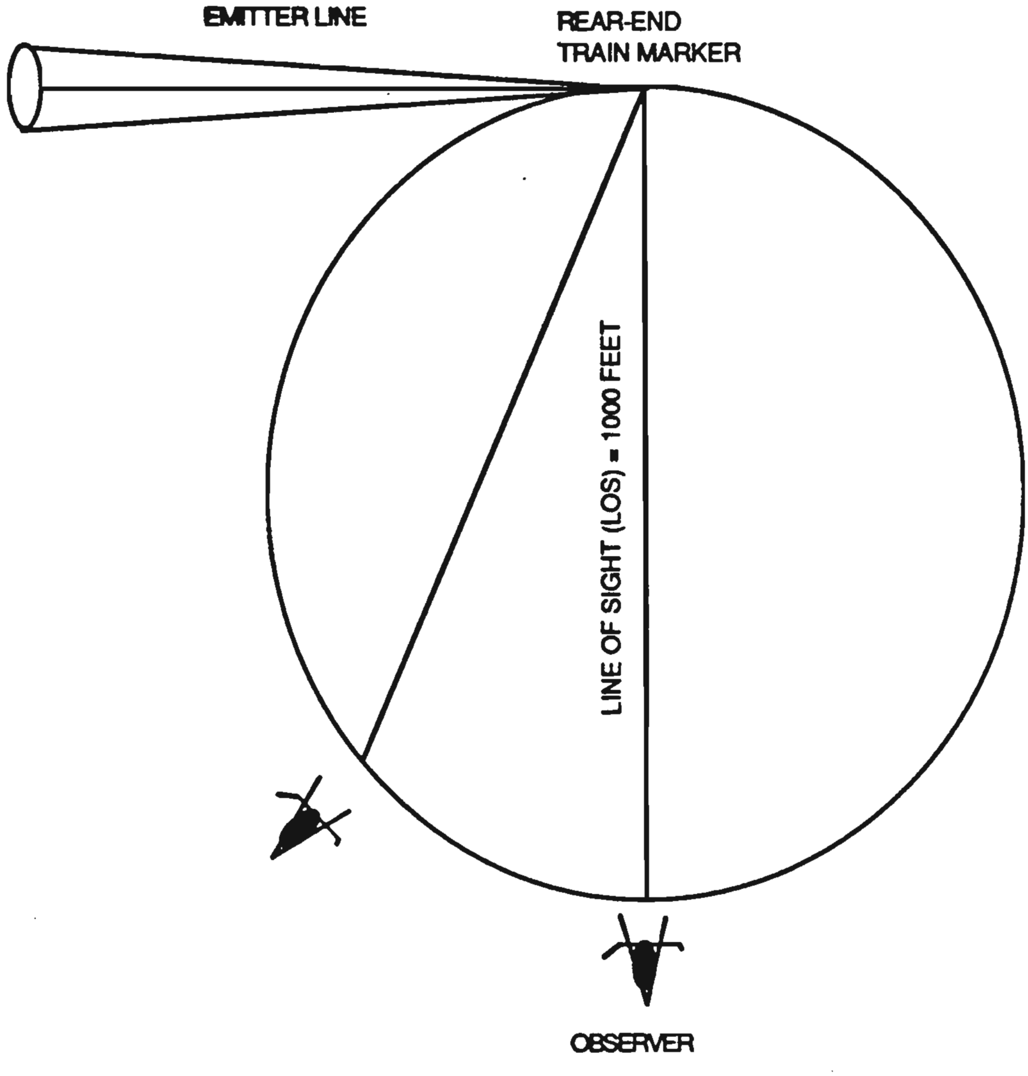

FIGURE D-1. GEOMETRY OF A CURVED TRACK APPROACH TOWARD A REAR-END TRAIN MARKER

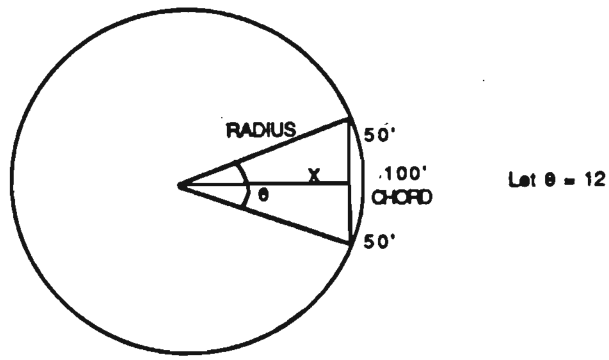

FIGURE D-2. GEOMETRY OF THE DEFINITION OF DEGREE OF TRACK CURVATURE

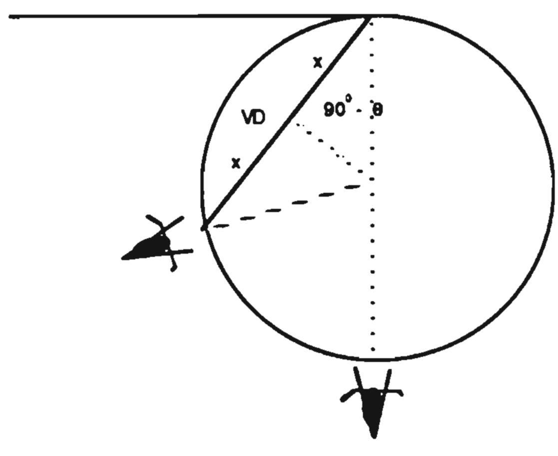

FIGURE D-3. GEOMTRY OF THE FORMULA FOR COMPUTING VIEWING DISTANCES

$\theta = 2 * \arcsin(50'/500') \simeq 11.5°$

Circular distance: The circular distance (i.e., track stopping distance) associated with any detection angle, θ, is given by:

Circular distance = CD = $\theta *2r = \theta*(1000')$

where $0 \leq \theta \leq \pi/2$ radians,

θ is "viewing angle", i.e, angle between marker's emitter line and O's line of sight.

The Federal Railroad Administration (FRA) has indicated they want markers to be detectible such that, assuming a "slow approach" (15 mph), there is at least 1000' of track stopping distance available to the locomotive engineer upon detecting the marker of another parked or slow-moving train. Excluding observer reaction time, the momentum of the train, the delays associated with the braking system, etc., Given a circular track of radius 500', a 1000' radial stopping distance implies that marker's should be detectible at a viewing angle, θ, of 57.3° or more, i.e.,

$1000' = \theta * (1000')$

$1000'/1000' = \theta$

$\theta = 1$ radian $= 57.3°$

Marker rate of turn: One intent of the field test was to simulate a 15 mph (i.e., 22'/sec) approach on 11.5° track. To determine the rate at which the marker should be rotated, for a circular track of radius 500',

a) Note that the circumference of the half circle is C' = 1570.8';

b) at 22'/sec, it would take a train 1570.8'/22'/sec = 71.4 sec to drive around the half circle;

c) assuming up to 90° of marker rotation in this study,

Marker rate of turn = 90°/71.4 sec = 1.26°/sec

The field test rate of turn was rounded to 1.25°/sec for ease of calibration.

Viewing distance: (See Figure D-3). At a detection angle, θ, the operator's line of sight forms a chord with one end attached at the marker, the other end at the observer's eye. From this, the viewing distance is computed as follows:

$$\cos(90° - \theta) = x/r \implies x = r * \cos(90° - \theta) \quad \text{for} \quad 0 \leq \theta \leq 90°$$

and Viewing Distance = VD = $2 * (r * \cos(90° - \theta))$ for $0 \leq \theta \leq 90°$

For example, with a detection angle of 85° and 11.5° track, the viewing distance (in a real world setting) would be:

$$VD = 2 * (500' * \cos(90^{o} - 85^{o})) = 996'$$

Recall that subjects in the field test always worked at a viewing distance of 1000'. The above calculations indicate that, over the range of detection angles observed in this test, small differences between actual and simulated viewing distances exist. While not empirically evaluated, these are differences are considered negligible. This is because the markers acted essentially as point sources of light and detection is thought to be essentially a form of intensity discrimination of the object from its surround (Riggs, 1971, p. 290).

Taken together, the above results suggested an alternative methodology which would make it easier to set up trials and collect data from more observers (under different conditions). As an observer travels around a bend and approaches a train marker, the angle θ between the marker's emitter line and the observer's line of sight grows smaller and this 'exposes' more of the marker to the observer. The angle θ, then, determines the marker's detection. The angle can also be directly related to stopping distances as was previously demonstrated. It was then conceivable to conduct marker detection tests with markers mounted on a rotating stand or turntable. An observer was situated at a fixed distance of 1000' from the turntable. A trial started with an angle of 90° (or more) between the emitter line and the observer's line of sight so the observer could not see the marker. The turntable was then rotated slowly toward the observer until the observer signaled that he/she detected the marker. The detection angle was recorded as the dependent variable and then used to assess the effects of various markers (and other factors) on the ability of human observers to see them.

APPENDIX E

STATISTICAL TESTS FOR MARKERS

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STATISTICAL TESTS FOR MARKERS

An Analysis of Variance (ANOVA) was performed using SAS, a software system for data analysis. An ANOVA is a statistical technique that is used to study the variability of data. Several values are calculated as a result of the ANOVA. These are:

F = the ratio of [Variance explained by factors]/[Variance left unexplained]

P = the probability or likelihood of saying that a significant difference exists between markers when there really is no significant difference.

MS_e = Mean Squared Error, the variability in the results which is not attributed to the marker.

ANOVA results for all markers are as follows:

F = 5282.82

P = < 0.0001

MS_e = 6.86

Duncan's Test. This is a "post-hoc" test of pair-wise comparison of measurements upon finding the significance, F. Even though all markers were equally acceptable according to the 1000 ft stopping distance criterion, there were statistically reliable differences among them, $F(7,161) = 5282.82$, $P < 0.0001$, $MS_e = 6.86$. Duncan's multiple range test indicated that, with alpha = .05, the mean detection angles were significantly different among markers E, D, H, and A; these are Star yellow/no blink, star red/blink, star red/no blink, and star yellow/no blink markers, respectively. Markers C, F, and G (TCS yellow/blink, TCS red/blink, and DSL markers, respectively) were significantly different for those just listed but not among themselves. Finally, Marker G (the Pulse LED) was significantly different from the other markers.

Means for red and yellow markers, averaged over both marker manufacturers, were not statistically different ($F(1,23) = .07$, $P < .7974$, $MS_e = 9.46$). Means for Star and TCS markers, averaged over red and yellow, were statistically different ($F(1,23) = 17353.0$, $P < .0001$, $MS_e = 6.56$). There was also a significant Color x Manufacturer interaction ($F(1, 23) = 79.79$, $P < .0001$, $MS_e = 9.17$).

The analysis of variance indicated no significant main effect of color ($F(1, 23) = 2.32$, $P < .1411$, $MS_e = 6.41$). Similarly, there was no main effect for cycle ($F(1, 23) = 0.21$, $P < .7277$, $MS_e = 11.7$). There was, however, a significant interaction between color and cycle ($F(1,23) = 89.86$, $P < .0001$, $MS_e = 11.2$).