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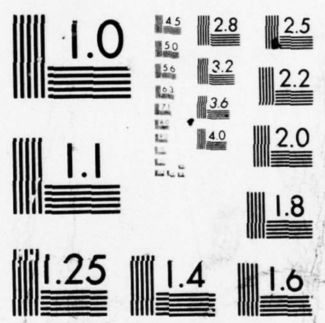

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LEVEL II

TECHNICAL REPORT: NAVTRAEQUIPCEN IH-305

COLOR ACUITY VISION TESTING FOR LASER PERSONNEL

DENIS R. BREGLIA
Advanced Simulation Concepts Laboratory
Naval Training Equipment Center
Orlando, FL 32813

November 1978

Interim Report for Period July 1978 - August 1978

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NAVAL TRAINING EQUIPMENT CENTER

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Visual acuity, color discrimination, and spectral sensitivity tests were administered to a group of personnel who had been exposed to laser radiation during the normal course of their research investigations. The same tests were also administered to a group of non-laser personnel. The test equipments and procedures are described. The test results indicate no significant differences between the two groups.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

SECTION I

INTRODUCTION

Recent investigations by Dr. Harry Zwick (Ref. 4 and 5) at Letterman Army Institute of Research (LAIR) indicate that there may be deleterious effects on observers who view laser displays even though the exposures involved are well below the current laser safety standards. This study was performed to determine whether individuals who had received prolonged exposure to low levels of laser radiation during the normal course of their research investigations had any significant visual dysfunction when compared to individuals who had received no such exposure.

This report includes a brief discussion of the theoretical aspects of vision as well as a description of the experimental procedures and results of Dr. Zwick. A description of the experimental equipments, procedures, subjects, and results of this study follows.

SECTION II

DISCUSSION

INTRODUCTION

The subject of human visual perception is much too broad and complex to treat in depth in this report. However, a brief discussion of some of the attributes of vision is in order to explain the reasons and procedures used in the experiments. The topics to be discussed in this section include visual acuity, luminance, vision: photopic (day) and scotopic (night), and visual dysfunctions as described in Dr. Zwick's experiments.

VISUAL ACUITY

The ability to discriminate between fine details of a test pattern is termed visual acuity. Three commonly used test patterns are the Landolt ring, the parallel-bar pattern (e.g., the USAF Resolving Power Test Target 1951) and the letters of the Snellen alphabet (e.g., a normal eye chart), (Ref. 1 and 2). The numerical value of acuity is the reciprocal of the angle, in arc minutes, subtended by the width of a stroke or gap when the pattern or its orientation can just be distinguished. An acuity of 1.0 implies that the unit width subtends an angle of 1.0 arc minute. This corresponds to a gap width of 1.0 arc minute in the Landolt "C" or a center-to-center distance between two successive black lines in a parallel-bar pattern of 2.0 arc minutes. Snellen letters used in a standard eye chart measure 5 arc minutes in height for 20/20 vision which corresponds to an acuity of 1.0. The three typical test patterns are depicted in figure 1.

LUMINANCE

Light is electromagnetic radiation which causes visual sensation in a human observer by the stimulation of the retina of his eye. Luminous flux is the time rate of flow, emission, or incidence of light. Luminance is the luminous flux per unit solid angle emitted per unit projected area. Luminance is practically synonomous with the term brightness. The standard units for measuring luminance are candela per square meter (cd/m^2). A footlambert is equal to 3.43 cd/m^2.

Luminance is not a purely physical quantity since it involves the interaction of radiant energy (which is a physical quantity) with the human observer's eye-brain perception processes (a psychological system). The measurement of luminance is based on the acceptance of certain psychological data. These data were gathered using a specific group of observers. The adoption of these data was arbitrary since somewhat different data would have been obtained from another group of observers or even the same group under different conditions. However, the standard luminosity data has been accepted internationally and is used to establish photometric quantities by definition. The unit of luminous flux is the lumen. Luminosity is the ratio of lumens per watt of any kind of radiant energy. The maximum value of absolute luminosity is 680 lumens/watt for radiant electromagnetic energy having a wavelength of 555 nanometers. All photometric units are based on data taken under daylight conditions (photopic vision).

(a) LANDOLT RING

(b) SNELLEN E

(c) PARALLEL BAR

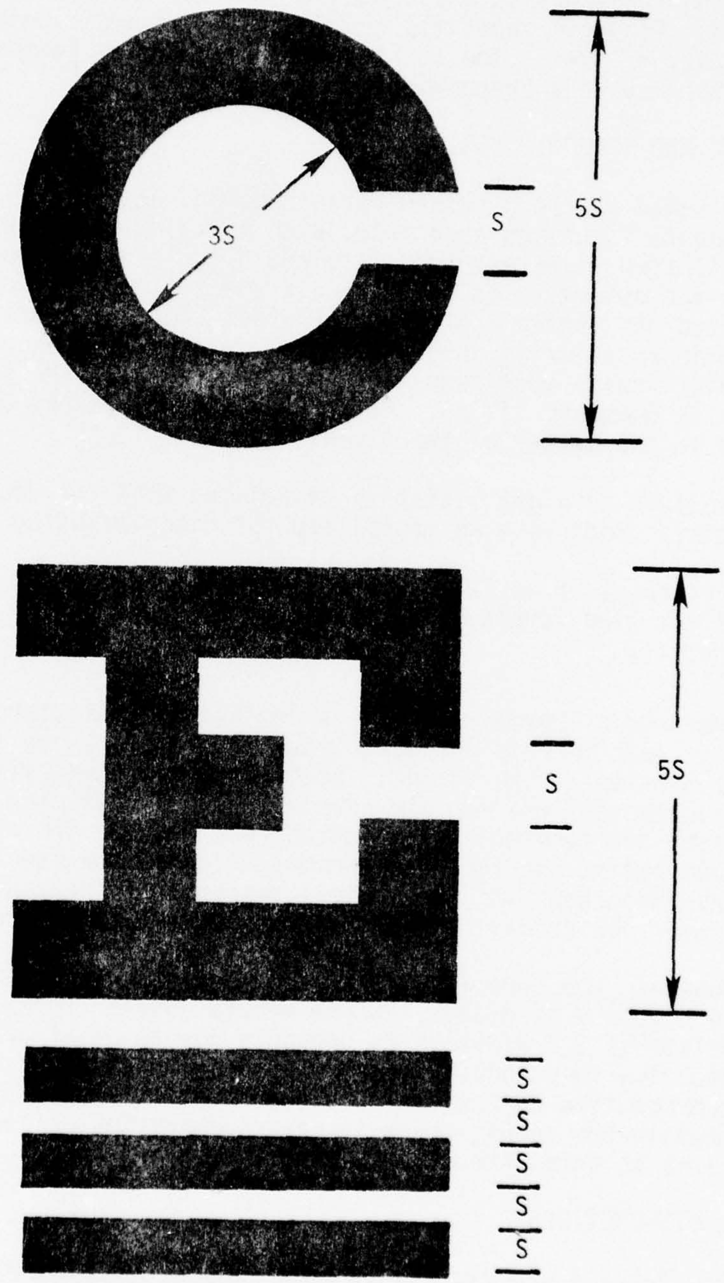

Figure 1. Test Patterns for Acuity Measurements

Figure 2 shows relative luminosity as a function of wavelength for both photopic (day) and scotopic (night) vision. The relation between visual acuity and luminance as measured with Landolt broken ring is depicted in figure 3. Figure 4 shows the wavelength of maximum luminosity as a function of adaptation level. The shift toward the blue as luminance decreases is called the Purkinje Phenomenon.

PHOTOPIC AND SCOTOPIC VISION

As noted in the previous paragraphs and depicted in figure 2, there are two response functions associated with normal vision. Photopic vision response is associated with moderate and high levels of luminance and is attributed to the detectors called cones in the retina. Although it has been postulated that there are three different kinds of cones (corresponding to three primary colors), no histological or other evidence has been found which could distinguish such cones in the human retina. The perception of color is limited to photopic vision. Cones have their greatest density in the fovea located in the center of the visual field.

Scotopic or night vision is associated with the detectors called rods in the retina. Rods have no capability for discriminating color.

Luminances up to 10^{-4} cd/m^2 can be utilized without interfering with dark adaptation. The levels utilized in photopic vision are of the order of $100 cd/m^2$.

Emmetropia (normal vision) is defined as that status of eye with accommodation at rest wherein incident image rays converge to form the circle of least confusion at the retina. Ametropia (deficient vision) includes myopia (nearsightedness) wherein the circle of least confusion is formed in front of the retina and hyperopia (farsightedness) wherein the circle of least confusion is formed behind the retina. Accommodation is the function of the eye whereby the converging power of the optical system is increased so that light diverging from a near source may be brought to a focus upon the retina.

However, the chromatic aberration and the Purkinje phenomenon only account for 0.4 diopters of myopia. Night myopia totals approximately 2.0 diopters. The additional 1.5 diopters is probably due to night presbyopia (a loss of accommodative function). There is evidence that the receptors which produce the accommodative reflex are the foveal cones; hence, at light levels too low to stimulate the cones, there is no accommodation reflex. Rod vision is insufficient to stimulate accommodation.

VISUAL DYSFUNCTIONS

Dr. Zwick's experiments at LAIR suggest that prolonged viewing of low-level laser radiation environments can produce permanent changes in visual processes that underlie normal human photopic and scotopic vision. Dr. Zwick believes that the coherence of the laser light is implicated as a significant factor in inducing these effects.

Figure 5 shows the experimental apparatus used at LAIR to expose and measure visual functions of rhesus monkeys. The monkeys were tested for

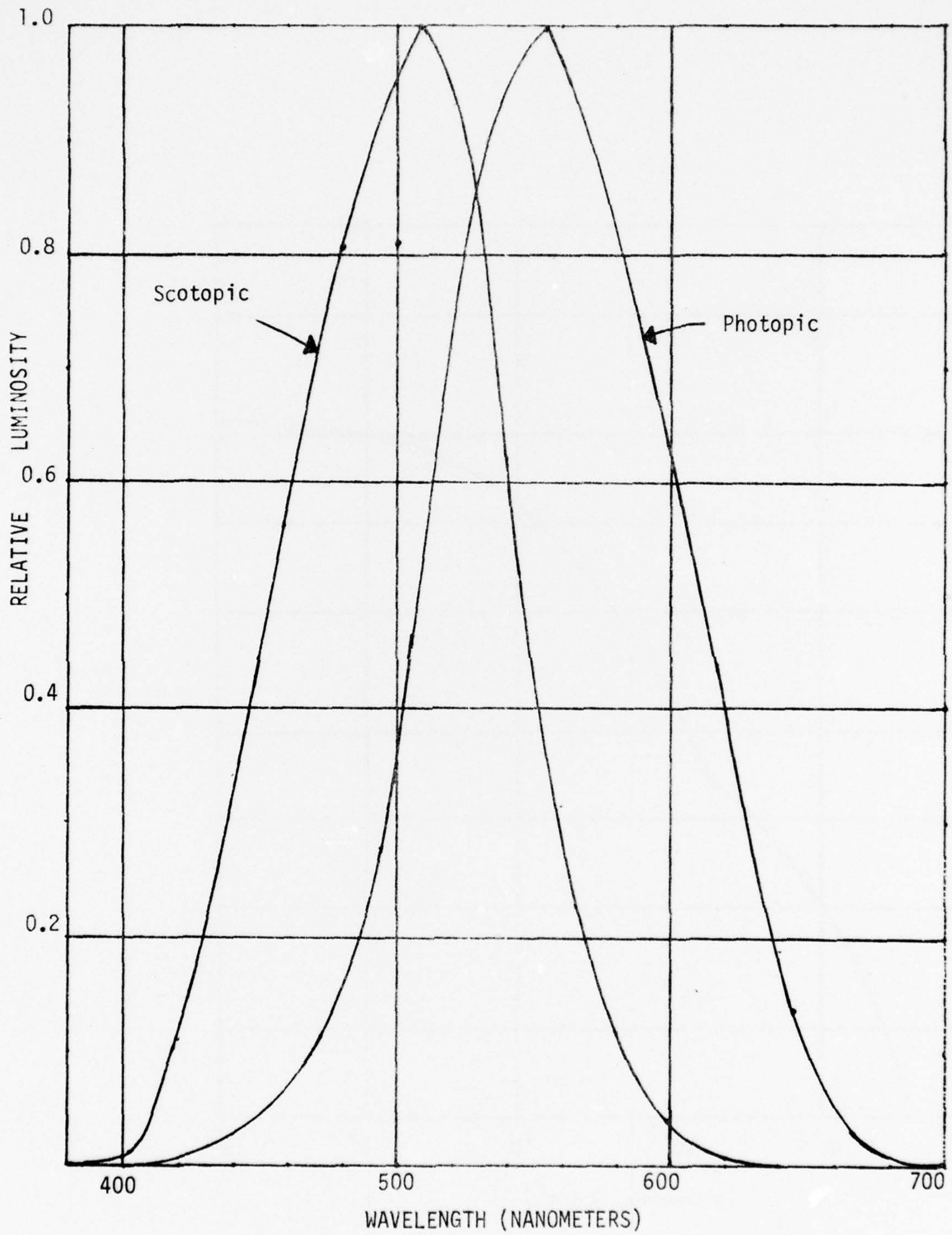

Figure 2. Relative Luminosity vs. Wavelength

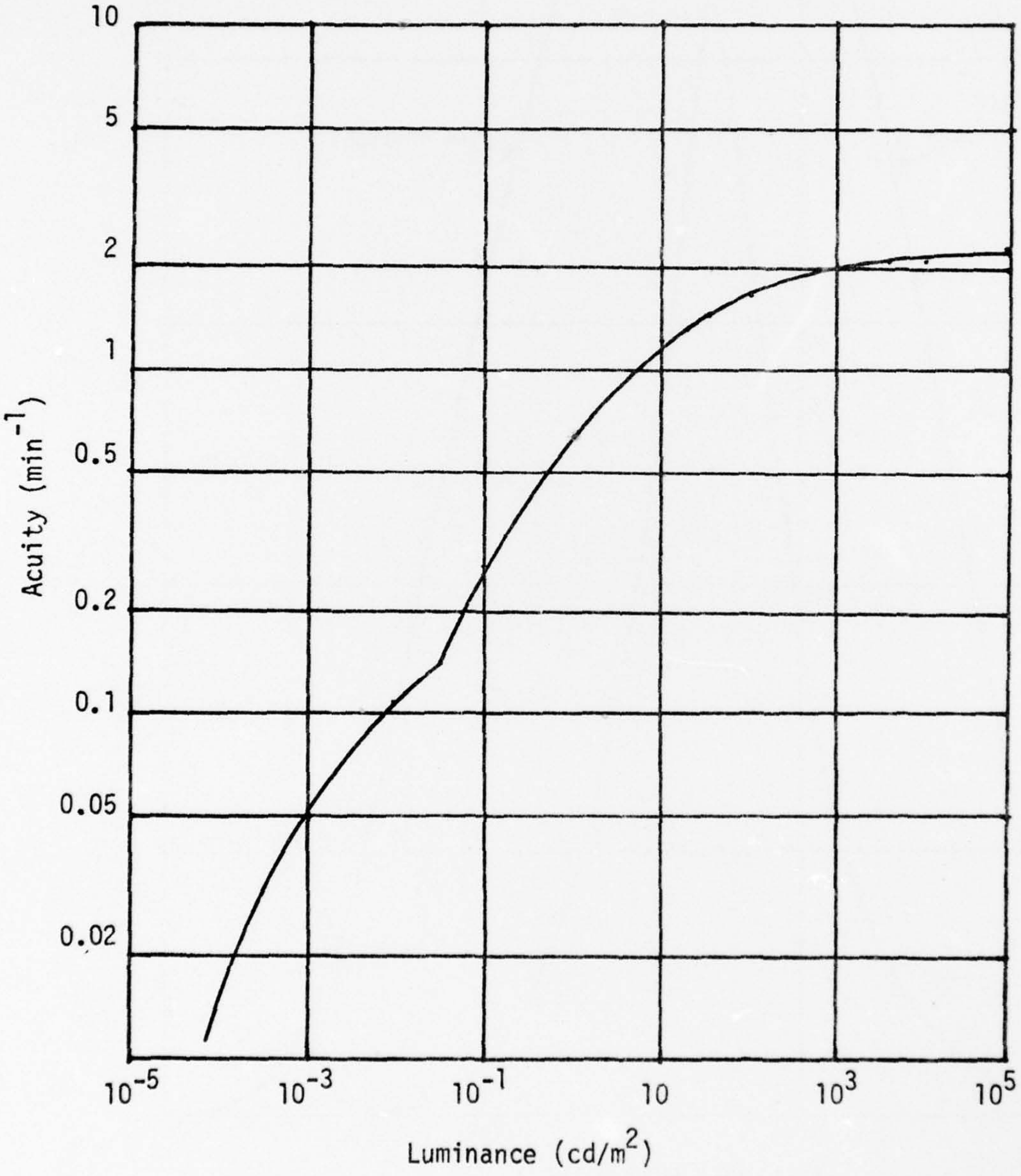

Figure 3. Acuity vs. Luminance for Landolt Ring

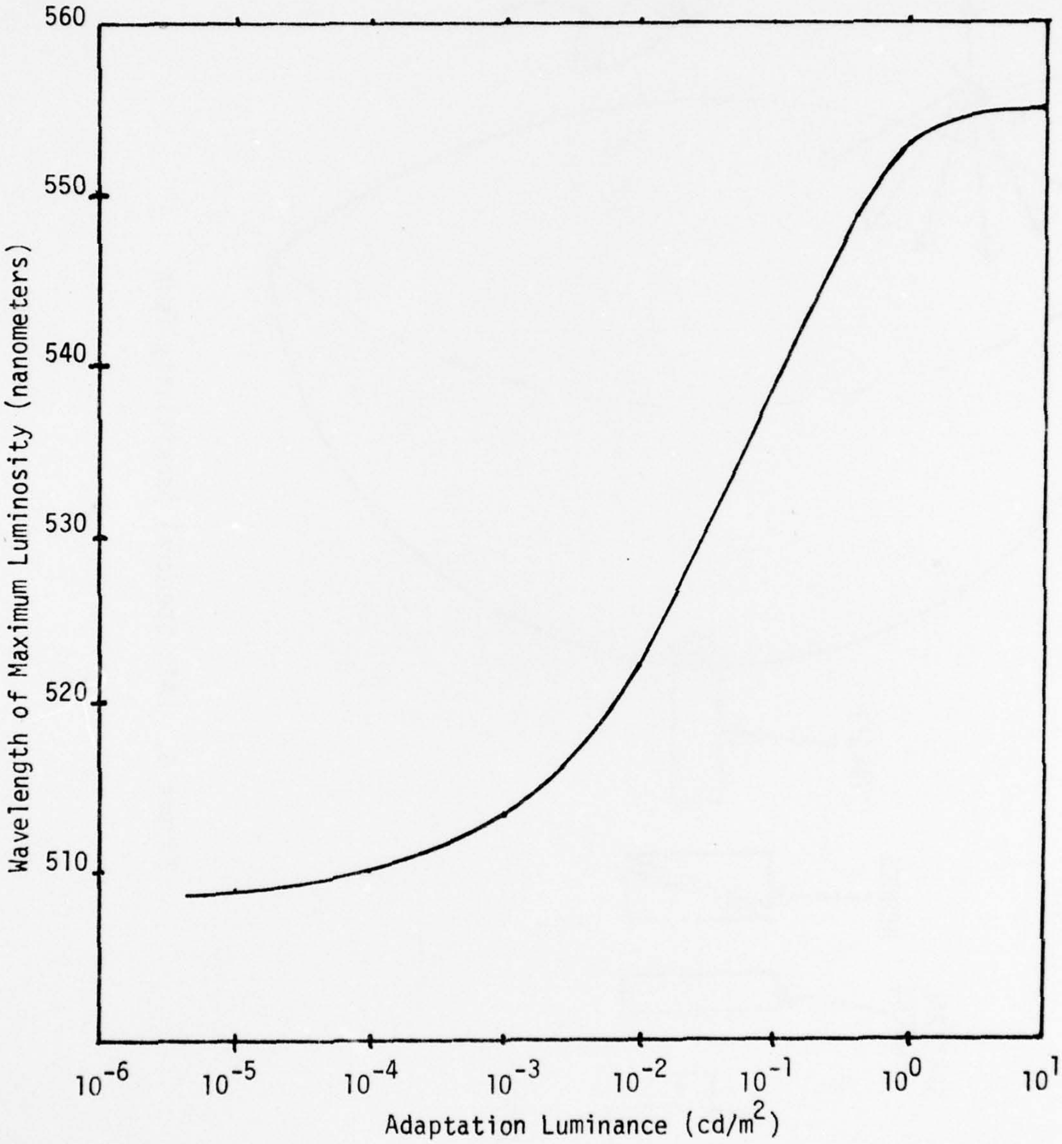

Figure 4. Wavelength of Maximum Luminosity vs. Adaptation

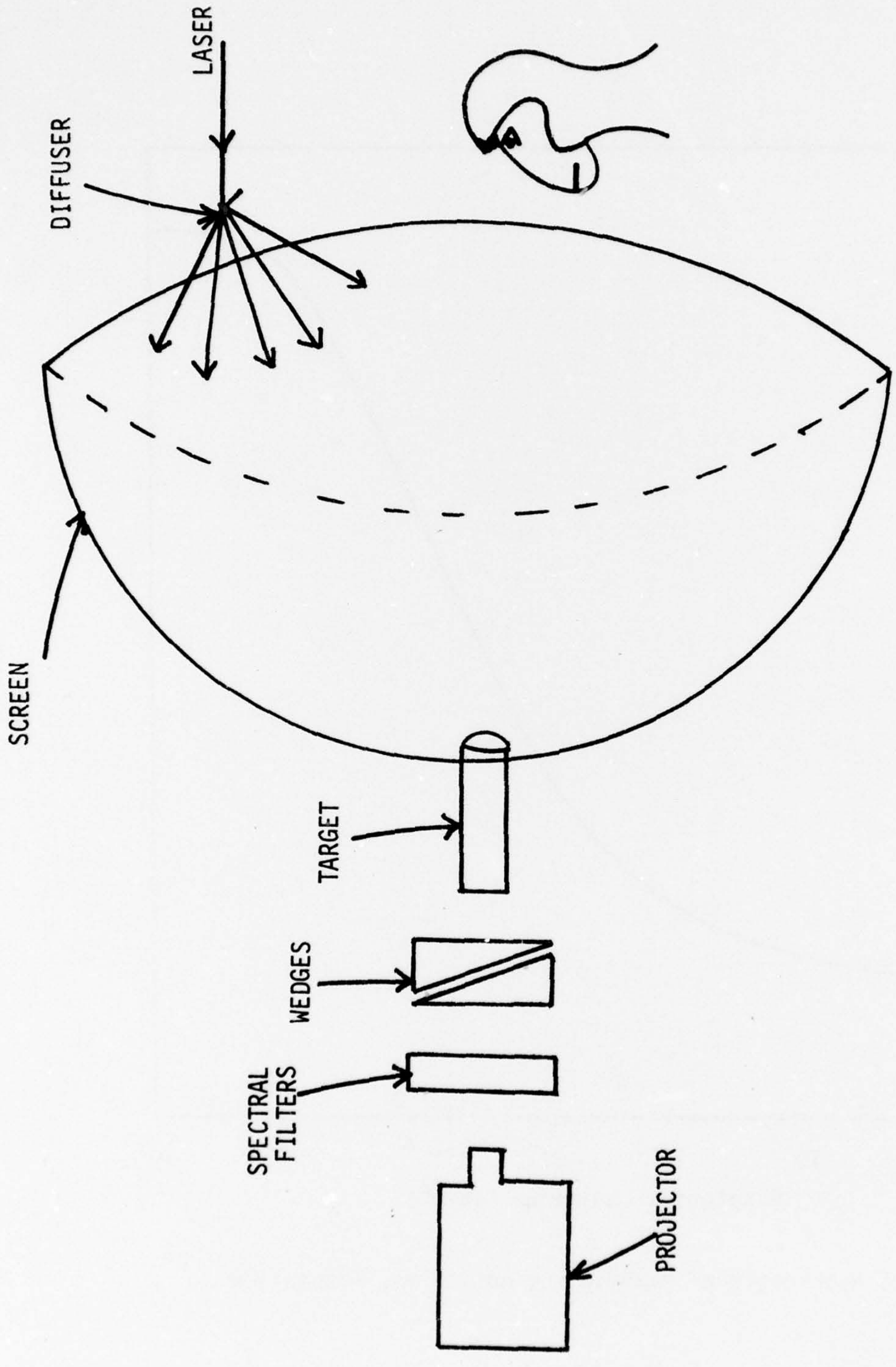

Figure 5. LAIR Spectral Sensitivity Test

spectral sensitivity, pre- and post-exposure, to laser light. The spectral sensitivity was measured by determining the background luminance required in small spectral bands throughout the spectrum for the monkey to correctly determine the position of the gap in a Landolt ring of a given size. The luminance of the spherical screen for exposure was approximately 25 cd/m^2 using the 514.5 nm spectral line from an argon ion laser. The Landolt ring gap sizes varied from 7.14 to 0.54 arc minutes (acuities of 0.14 to 1.85, respectively).

Exposure time consisted of daily two-hour continuous exposure periods for 19 days for a total of 38 cumulative hours for one rhesus monkey and 20 cumulative hours for another rhesus monkey.

Results indicate a permanent depression of spectral sensitivity by approximately one log unit at the 1.85 min^{-1} acuity criterion. There was no significant permanent depression at the 0.14 acuity criterion. The maximal depression for the 1.85 min^{-1} acuity criterion occurred at 540 nm.

SECTION III

TEST EQUIPMENT AND METHODS

INTRODUCTION

Several personnel of the Naval Training Equipment Center have worked with visible lasers during the course of their research investigations. Although these personnel were not exposed to laser radiation for the purposes of this test, they had received cumulative doses well in excess of the 20 to 38 hours to which the subjects of Dr. Zwick's experiments were exposed. Accordingly, visual performance measurements were made with these personnel as subjects. A group of personnel who had never been exposed to laser radiation underwent the same tests to act as a control group.

The testing of both subjects and controls consisted of four separate tests plus an interview.

VISUAL ACUITY

All personnel were tested for visual acuity utilizing a Sargent-Welch School Chart No. 3539. The testing was accomplished at recommended distance of 20 feet under normal office lighting (15 cd/m^2). The surround was relatively constant consisting of a 1.5 meter diameter diffuse white screen. Subjects were scored using the Snellen fraction, the distance, the number missed, and the number in the row for each eye individually. Each of the personnel used his own corrective lenses or contacts if he were ametropic. No attempt was made to correct any refractive errors.

COLOR DISCRIMINATION

All personnel were tested for color discrimination using the Farnsworth-Munsell 100-Hue Test (available from Munsell Color, MacBeth Division, 2441 North Calvert Street, Baltimore, Maryland). This test consists of 85 color caps which the subject must arrange in order according to color. The purpose of this test is to determine type and degree of color defectiveness.

COLOR DEFECT

An additional color discrimination test using the Dvorine Pseudo-Isochromatic Plates (The Psychological Corporation) was also administered to each of the personnel.

SPECTRAL SENSITIVITY

Figure 6 shows the experimental arrangement used to measure spectral sensitivity. The target generator produced a back lit diffuse screen whose color could be varied by selection of the appropriate narrow band spectral filter from a set of 21 filters in the filter bar. An opaque Landolt broken ring of a particular size was placed in front of the diffuse screen. The gap could be positioned left, right, up, or down. The luminance of the screen was varied by a variable transformer controlling the voltage on the incandescent lamp. Luminance at threshold was measured using a Spectra Photometer (Photo Research

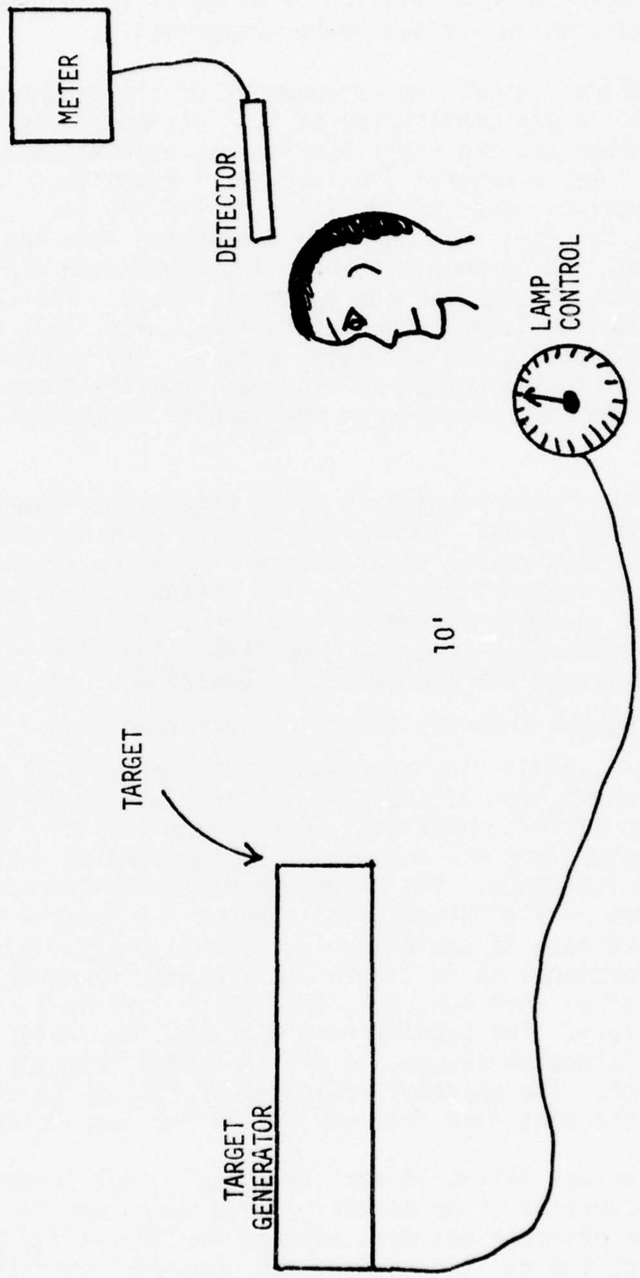

Figure 6. Spectral Sensitivity Test Arrangement

Inc., Burbank, CA). Since this experiment apparatus was assembled at Naval Training Equipment Center, a more detailed description is in order as opposed to the three other tests which are available commercially.

TARGET GENERATOR. Figure 7 shows the arrangement of the target generator. The light-tight enclosure was constructed of 0.5" plywood. The overall length was approximately 1 meter and the cross section was approximately 0.18 meters square. The lamp used was a General Electric No. 1 Photoflood (ANSI Lamp Code BBA) drawing a nominal power of 250 watts at 115-120 VAC. A light-tight fan and vent was used for cooling. Both the condensing lens and field lens had 90 mm focal lengths and 60 mm diameters. The condensing lens imaged the lamp onto the field lens through the one spectral filter. The condensing lens was located 180 mm from the lamp and the field lens. The field lens was located 360 mm from the opal glass diffusing screen. The uniformity of luminance across the diffusing screen as measured from the observer's position using a 2-arc minute sampling aperture in the Spectra photometer was better than 5 percent.

The spectral filters were mounted in a 0.9 meter long frame having a cross section of 15 mm by 40 mm. Individual filters were cylindrical, having diameters of 25 mm and thicknesses varying from 3 to 9 mm. Each filter was mounted in a round hole in the filter bar. The optical characteristics of each filter are listed in Table 1. Detents in the filter bar allowed the operator to select a particular filter in the dark. The size of the opal glass rear projection screen was approximately 90x120 mm. The angles subtended by the target screen from the observer's position were 2.2° horizontal by 1.5° vertical. The Landolt ring consisted of an opaque ring on a clear plastic disc. The transmission of the clear plastic was approximately 95 percent throughout the visible spectrum. This slight loss of light to the observer was incorporated into the correction factor used to get a true reading of background luminance. The target Landolt rings were fabricated by successive applications of flat black paint through a screening mask. The sizes of the rings were made to conform to 2, 5, and 10 arc minute gaps (with other dimensions proportional as in figure 1(a)) at the observer's distance of 10 feet. The gap sizes were 1.8, 4.4, and 8.9 mm for the 2, 5, and 10 arc minute gaps, respectively. The Landolt ring disc had four holes drilled at the 3, 6, 9, and 12 o'clock positions. A pin protruded from the screen at the 12 o'clock position. The operator could orient the gap to any of four positions by hanging the ring disc from any one of the four holes.

OBSERVER. The observer was seated 10 feet from the target screen. He wore corrective lenses or contacts if he normally would wear them for seeing at a 10-foot distance. The observer was dark adapted for 30 minutes prior to the testing period. During the testing period, the observer controlled the luminance of the display using a variable transformer. The observer was instructed to increase the luminance until he could just make out the orientation of the gap. He would then tell the operator. Correct responses were recorded together with a reading of the luminance of the background screen. If the observer's response were in error, he was instructed to decrease the luminance to zero, the operator changed the position of the gap, and the process was repeated until the response was correct. The observer was instructed to change luminance only by increasing, no decreases were allowed.

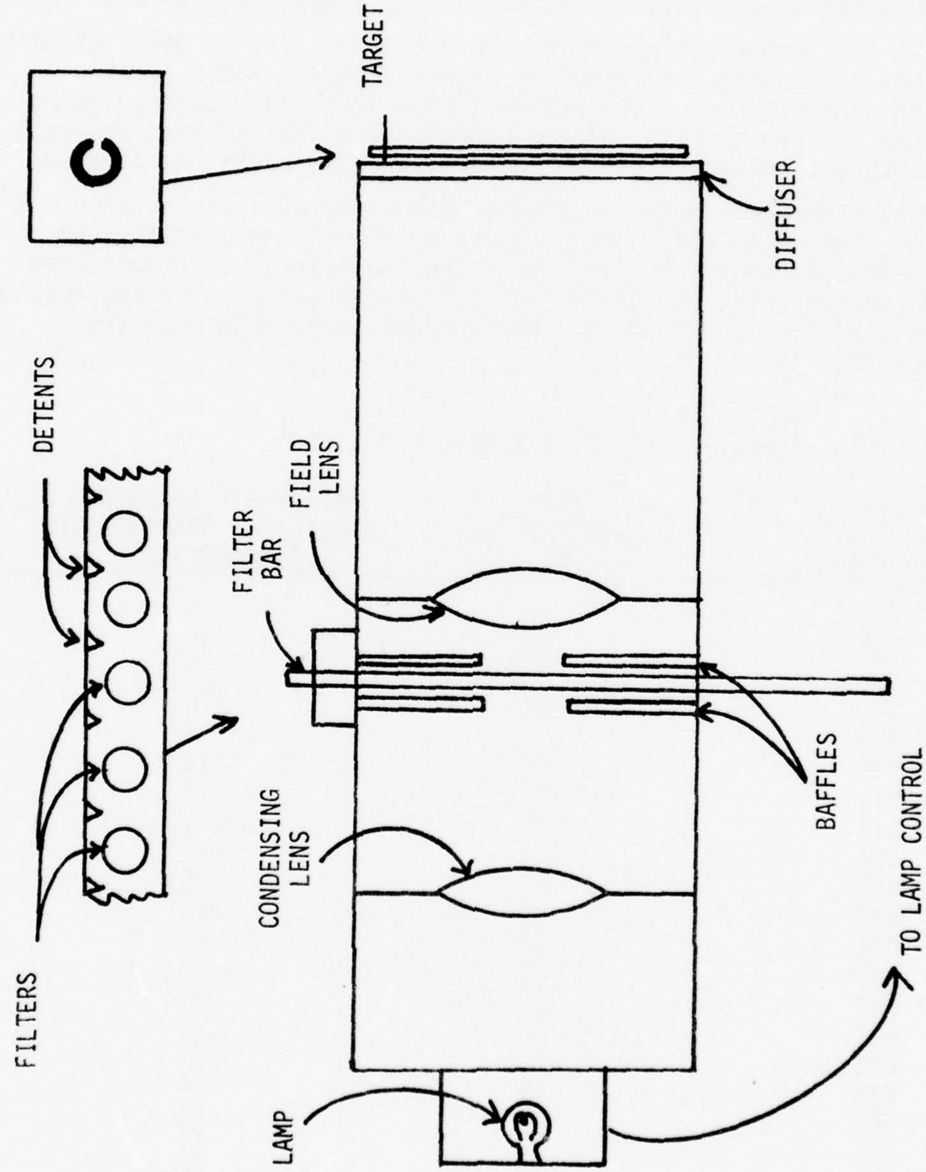

Figure 7. Target Generator

The observer was given no time limit to make his determination. He was told to use any technique (looking off target, blinking, staring, etc.) to make a determination. The observer viewed each target monocularly using a card to obscure the eye not being tested.

PHOTOMETER. The Spectra photometer used for luminance measurements read in footlamberts. (A footlambert is equivalent to 3.43 cd/m^2.) The units of footlamberts are based on photopic responses of standard eyes. There is no scotopic standard of luminance. Calibration tables supplied with the instrument together with the transmission of the Landolt ring disc allowed accurate measurement of absolute luminance of the background. The probe was located slightly above the observer's head, looking at the background screen with a 1° acceptance angle. The meter and a second operator were located in another room to record responses and meter readings. The two operators communicated with an intercom system. The photometer was calibrated using a radioactivated phosphor internal calibration standard. Measurements were made with the Landolt disc removed.

TABLE 1. CHARACTERISTICS OF SPECTRAL FILTERS

FILTER #	PEAK WAVELENGTH (NANOMETERS)	PEAK TRANSMISSION (%)	WAVELENGTH BANDWIDTH AT HALF PEAK TRANSMISSION (NANOMETERS)
1	434	55	13
2	452	58	17
3	462	48	17
4	481	54	14
5	488	55	7
6	495	68	16
7	511	67	15
8	515	55	7
9	525	46	20
10	542	67	16
11	555	59	15
12	574	58	12
13	599	69	12
14	617	53	23
15	631	68	15
16	633	55	7
17	645	55	16
18	660	66	14
19	676	63	13
20	691	52	14
21	705	61	14

DATA REDUCTION. During the testing period, a data sheet was used to record uncorrected luminance threshold as a function of the eye used, the filter number, and the gap size. Figure 8 shows a blank data sheet. Correction factors for the transmission of the Landolt ring disc and the meter response relative to the standard observer curve were applied to the group averages. Table 2 shows the correction factors. The transmission factor is the inverse of the transmission of the plastic disc containing the Landolt ring. The response factor was taken from a table relating the instrument response to the standard observer response supplied by the manufacturer for the particular instrument used.

INTERVIEW. Each of the subjects was interviewed to determine estimated cumulative exposure time to various types of laser light. There was no attempt to quantify the level of exposure. The subjects were asked to estimate the total time they were in an environment in which the only source of light was a laser. Note that the principle emission lines on the various lasers are: 633 nm, HeNe; 515, 488 nm, Ar; and 647, 568, 531, 476 nm, Kr.

TABLE 2. CORRECTION FACTORS

FILTER NUMBER	TRANSMISSION FACTOR	RESPONSE FACTOR	TOTAL FACTOR
1	1.05	1.65	1.73
2	1.04	1.28	1.33
3	1.04	1.27	1.32
4	1.04	1.07	1.11
5	1.06	1.00	1.06
6	1.06	.95	1.01
7	1.04	1.01	1.05
8	1.04	1.03	1.07
9	1.05	1.03	1.08
10	1.04	1.00	1.04
11	1.04	1.01	1.05
12	1.05	1.00	1.05
13	1.06	1.08	1.14
14	1.05	1.88	1.97
15	1.04	2.80	2.91
16	1.04	2.90	3.02
17	1.04	3.71	3.86
18	1.04	4.36	4.53
19	1.04	5.00	5.20
20	1.04	4.10	4.26
21	1.03	3.65	3.76

THRESHOLD TESTS

Filter #	λ in Å	C = 2' Left	C = 2' Right	C = 5' Left	C = 5' Right	C = 10' Left	C = 10' Right
1	4336						
2	4515						
3	4616						
4	4811						
5	4880						
6	4946						
7	5105						
8	5145						
9	5247						
10	5421						
11	5551						
12	5736						
13	5993						
14	6172						
15	6305						
16	6328						
17	6452						
18	6601						
19	6764						
20	6912						
21	7047						

Figure 8. Data Sheet

The wavelengths are related to color by Table 3.

TABLE 3. WAVELENGTH VS. COLOR

WAVELENGTH RANGE nm	COLOR
380-450	violet
450-490	blue
490-560	green
560-590	yellow
590-630	orange
630-760	red

DIFFERENCES. The major differences between the NAVTRAEQUIPCEN tests and the LAIR tests were:

a. Seventeen human subjects in the NAVTRAEQUIPCEN tests versus two monkeys in LAIR tests.

b. Three meter distance to target in NAVTRAEQUIPCEN tests versus one meter distance in LAIR tests.

c. Monocular testing for 34 separate readings in NAVTRAEQUIPCEN tests versus binocular viewing for two readings in LAIR tests.

d. None of the seven laser subjects in the NAVTRAEQUIPCEN tests were exposed to the uniform hemispherical illumination used in the LAIR tests.

SECTION IV

RESULTS

Tables 4, 5, and 6 contain the data reduced from the various tests administered.

Table 4 contains eight listings for each filter, i.e., mean and standard deviation for both laser and control group for both 2' and 10' criterion. The threshold luminance values are given in units of footlamberts (1 footlambert = 3.43 cd/m^2). Note that the expression of luminance is read as a number times a power of 10, e.g., 3.3E-2 = 3.3×10^{-2} = 0.033. Due to time and manpower limitations, the 5' criterion test was not administered nor were the 2' and 10' both administered to all personnel. The raw data in the appendix also shows some gaps where an individual could not discern the target at the maximum luminance of the target generator (for a particular filter). In the calculation of the means and standard deviations, all measured data points were included. Missing data were ignored. No attempt was made to eliminate "wild" data points.

The sample sizes were seven laser personnel designated L1 through L7 (14 eyes) and 10 non-laser personnel designated C1 through C10 (20 eyes).

The means and standard deviations were corrected using factors in Table 2. Figure 9 shows spectral sensitivity curves as plotted for the means of both groups at both 2' and 10' criteria.

TABLE 4. SPECTRAL SENSITIVITY

LUMINANCE (FT-L)

10'

FILTER	LASER GROUP MEAN	LASER GROUP STANDARD DEVIATION	CONTROL GROUP MEAN	CONTROL GROUP STANDARD DEVIATION
1	1.8E-3	2.6E-3	1.9E-3	1.2E-3
2	1.2E-3	1.9E-3	2.0E-3	1.7E-3
3	1.1E-3	1.7E-3	2.9E-3	2.2E-3
4	6.9E-4	1.1E-3	3.6E-3	3.2E-3
5	9.0E-4	1.4E-3	3.3E-3	2.2E-3
6	4.9E-4	1.3E-3	2.8E-3	2.3E-3
7	8.3E-4	6.3E-4	3.7E-3	3.6E-3
8	8.5E-4	1.3E-3	3.0E-3	2.4E-3
9	9.6E-4	1.2E-3	4.1E-3	4.3E-3
10	9.6E-4	1.6E-3	3.8E-3	3.2E-3
11	9.6E-4	1.1E-3	3.2E-3	1.8E-3
12	8.9E-4	5.5E-4	3.7E-3	2.2E-3
13	1.9E-3	1.1E-3	4.0E-3	2.3E-3
14	3.7E-3	2.4E-3	6.5E-3	4.7E-3
15	3.8E-3	1.5E-3	5.5E-3	3.2E-3
16	3.9E-3	1.2E-3	5.7E-3	4.5E-3
17	5.0E-3	1.7E-3	6.2E-3	4.2E-3
18	5.9E-3	1.8E-3	9.1E-3	5.9E-3
19	8.8E-3	3.2E-3	1.1E-2	4.8E-3
20	9.8E-3	3.1E-3	1.2E-2	6.4E-3
21	1.1E-2	4.5E-3	1.2E-2	4.9E-3

2'

FILTER	LASER GROUP MEAN	LASER GROUP STANDARD DEVIATION	CONTROL GROUP MEAN	CONTROL GROUP STANDARD DEVIATION
1	1.3E-2	1.1E-2	2.4E-2	5.2E-3
2	2.5E-2	2.5E-2	5.3E-2	2.0E-2
3	3.7E-2	4.2E-2	7.0E-2	5.4E-2
4	4.2E-2	6.1E-2	1.2E-1	1.1E-1
5	2.9E-2	2.3E-2	1.5E-1	1.4E-1
6	3.0E-2	3.2E-2	1.7E-1	2.0E-1
7	3.3E-2	3.3E-2	1.2E-1	1.6E-1
8	9.0E-2	2.7E-1	1.6E-1	2.6E-1
9	3.5E-2	4.9E-2	1.7E-1	5.0E-1
10	2.4E-2	1.8E-2	5.9E-2	5.8E-2
11	3.8E-2	3.2E-2	7.2E-2	1.2E-1
12	3.8E-2	3.7E-2	3.9E-2	3.5E-2
13	4.7E-2	6.4E-2	4.4E-2	3.5E-2
14	7.9E-2	1.1E-1	5.3E-2	4.7E-2
15	1.2E-1	1.8E-1	5.5E-2	3.2E-2
16	6.6E-2	9.1E-2	5.4E-2	3.3E-2
17	8.5E-2	8.9E-2	8.9E-2	6.2E-2
18	1.6E-1	3.3E-1	1.1E-1	9.1E-2
19	1.2E-1	1.1E-1	1.2E-1	6.2E-2
20	1.4E-1	1.0E-1	1.1E-1	6.8E-2
21	6.8E-2	3.2E-2	9.4E-2	3.5E-2

TABLE 5. THREE TEST RESULTS

SUBJECT	SNELLEN AT 20 FEET LEFT	RIGHT	PI PLATES # MISSED	FARNSWORTH TOTAL ERROR SCORE
L1	20/20	20/20	0	36
L2	20/20	20/20	0	12
L3	20/15	20/15	0	36
L4	20/20-3/8	20/20-2/8	0	16
L5	20/15	20/15	0	4
L6	20/20	20/20	0	16
L7	20/15	20/15	0	4
C1	20/20	20/20	0	102
C2	20/30	20/30	0	8
C3	20/15	20/15	0	16
C4	20/15	20/15	0	8
C5	20/20	20/20	0	4
C6	20/15-3/10	20/30	0	4
C7	20/15-3/10	20/15-1/10	0	24
C8	20/15	20/15-2/10	0	29
C9	20/30-1	20/30-2/	0	20
C10	NONE ADMINISTERED			

TABLE 6. INTERVIEW

SUBJECT	AGE/SEX	EYE CORRECTION	LASER EXPOSURE (HOURS)
L1	35/F	Contacts	HeNe 50; AR 500
L2	34/M	None	Kr 200; HeNe 1500; AR 1,000
L3	56/M	Glasses	HeNe 500; AR 500
L4	42/M	None	HeNe 100; AR 500
L5	34/M	Contacts	Kr 1,000; HeNe 1,000
L6	45/M	None	HeNe 50; AR 50
L7	43/M	Glasses	HeNe 1,000; AR 1,000; Kr 1,000
C1	48/M	None	
C2	55/M	None	
C3	39/M	None	
C4	47/M	None	
C5	37/M	None	
C6	54/M	None	
C7	47/M	None	
C8	29/M	None	
C9	51/M	Glasses	
C10	50/M	Glasses	

Figure 9. Spectral Sensitivity Results

SECTION V

CONCLUSIONS

The results of this test program failed to show any significant difference between the laser group and the control group.

The spectral sensitivity results were such that the standard deviation or data spread for each of the means exceeded the difference between the two groups.

The Dvorine and Farnsworth test results were within normal limits for all personnel tested.

Several recommendations can be made for future test programs if they are to be implemented. A larger group of subjects who are more closely matched as to age and experience in detail seeing should result in more consistent data. The utilization of refractive correction to minimize the effects of night myopia prior to testing should also give less data variation. The experimental target generation system should be redesigned to allow more light transmission at the extreme reds and violets.

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APPENDIX A

RAW DATA SPECTRAL SENSITIVITY TEST
(METER READING AT THRESHOLD (FT-LAMBERTS))

L1

	10'		2'	
FILTER	LEFT	RIGHT	LEFT	RIGHT
1	6.0E-5	5.0E-5	1.5E-2	1.5E-2
2	7.0E-5	4.0E-5	1.0E-2	7.5E-3
3	4.0E-5	3.0E-5	1.5E-2	1.4E-2
4	1.5E-4	6.0E-5	1.5E-2	1.3E-2
5	8.0E-5	8.0E-5	1.6E-2	2.1E-2
6	1.1E-4	1.6E-4	1.3E-2	9.0E-3
7	1.3E-4	1.6E-4	1.4E-2	1.1E-2
8	8.0E-5	5.2E-4	1.2E-2	1.5E-2
9	1.0E-4	2.2E-4	2.2E-2	1.6E-2
10	5.9E-4	7.0E-5	2.5E-2	3.6E-2
11	1.6E-4	1.0E-3	1.6E-2	4.8E-2
12	6.5E-4	7.0E-4	2.1E-2	2.0E-2
13	1.5E-3	2.5E-3	1.5E-2	7.0E-2
14	1.8E-3	2.7E-3	1.3E-2	8.0E-3
15	1.1E-3	1.1E-3	6.0E-3	4.0E-3
16	1.1E-3	1.1E-3	1.0E-2	1.5E-2
17	1.3E-3	8.5E-4	1.1E-2	1.2E-2
18	8.0E-4	1.1E-3	1.2E-2	2.0E-2
19	1.5E-3	1.7E-3	3.3E-2	4.1E-2
20	2.2E-3	2.1E-3	2.6E-2	3.7E-2
21	2.9E-3	2.5E-3	2.4E-2	3.5E-2

L2

1	7.5E-4	2.5E-4	*	*
2	7.1E-4	1.1E-4	*	4.8E-2
3	5.1E-4	2.8E-4	1.2E-1	3.2E-2
4	6.4E-4	1.2E-4	1.9E-1	1.9E-2
5	2.2E-4	1.1E-4	6.6E-2	2.5E-2
6	4.3E-4	1.8E-4	1.2E-1	2.0E-2
7	4.4E-4	2.1E-4	2.0E-2	1.7E-2
8	1.1E-3	8.0E-5	2.7E-2	1.5E-2
9	3.1E-4	2.7E-4	8.7E-2	1.6E-2
10	1.9E-4	7.0E-5	3.7E-2	1.8E-2
11	4.8E-4	2.7E-4	4.1E-2	1.2E-2
12	7.2E-4	6.2E-4	1.4E-2	1.3E-2
13	1.0E-3	8.2E-4	1.0E-2	1.0E-2
14	7.0E-4	9.1E-4	1.5E-2	1.4E-2
15	6.9E-4	4.5E-4	6.0E-3	4.0E-3

L2 (Contd)

FILTER	10' LEFT	10' RIGHT	2' LEFT	2' RIGHT
16	6.2E-4	5.5E-4	1.0E-2	7.0E-3
17	9.1E-4	6.1E-4	7.0E-3	8.0E-3
18	8.7E-4	7.1E-4	8.0E-3	9.0E-3
19	7.6E-4	6.1E-4	5.0E-3	9.0E-3
20	1.2E-3	2.4E-3	9.0E-3	1.9E-2
21	1.8E-3	1.3E-3	1.6E-2	2.0E-2

*No reading at max luminance.

L3

1	4.6E-3	3.6E-3	*	1.4E-2
2	4.1E-3	3.7E-3	4.2E-2	5.2E-2
3	2.9E-3	3.7E-3	4.2E-2	4.9E-2
4	3.1E-3	2.3E-3	4.0E-2	4.0E-2
5	2.6E-3	4.3E-3	4.0E-2	4.3E-2
6	3.7E-3	3.3E-3	4.2E-2	3.3E-2
7	2.1E-3	1.3E-3	2.6E-2	3.1E-2
8	3.2E-3	3.2E-3	3.7E-2	3.5E-2
9	3.4E-3	2.8E-3	2.6E-2	1.6E-2
10	3.5E-3	4.8E-3	2.2E-2	1.6E-2
11	3.4E-3	2.3E-3	2.6E-2	3.7E-2
12	1.8E-3	1.9E-3	2.8E-2	2.1E-2
13	2.1E-3	3.5E-3	4.7E-2	3.1E-2
14	1.4E-3	4.3E-3	1.1E-2	3.2E-2
15	1.4E-3	1.0E-3	1.2E-2	6.4E-2
16	1.7E-3	1.2E-3	1.3E-2	2.6E-2
17	1.3E-3	1.3E-3	4.7E-2	3.0E-2
18	1.4E-3	1.6E-3	2.4E-2	3.8E-2
19	1.9E-3	1.6E-3	3.8E-2	8.1E-2
20	1.3E-3	3.3E-3	4.0E-2	5.5E-2
21	2.4E-3	2.3E-3	*	*

*No reading at max luminance.

L4

FILTER	10' LEFT	10' RIGHT	2' LEFT	2' RIGHT
1	N		*	*
2	O		*	*
3			*	4.0E-2
4	T		1.3E-1	4.5E-2
5	E		*	6.5E-2
6	S		3.0E-2	1.5E-2
7	T		1.2E-1	2.0E-2
8			9.5E-1	3.5E-2
9	A		1.7E-1	2.5E-2
10	D		7.0E-2	2.5E-2
11	M		1.3E-1	3.5E-2
12	I		1.1E-1	3.0E-2
13	N		2.2E-1	3.0E-2
14	I		9.5E-2	2.3E-1
15	S		1.1E-1	6.0E-2
16	T		*	1.4E-1
17	E		*	8.5E-2
18	R		2.8E-1	3.5E-2
19	E		1.8E-2	*
20	D		*	6.6E-2
21			*	*

*No reading at max luminance.

L5

FILTER	10' LEFT	10' RIGHT	2' LEFT	2' RIGHT
1	4.3E-4	6.0E-5	2.0E-3	5.0E-3
2	4.0E-5	4.0E-5	2.1E-3	7.0E-3
3	2.0E-5	2.0E-5	4.5E-3	7.0E-3
4	2.0E-5	1.0E-5	8.0E-3	6.8E-3
5	5.0E-5	4.0E-5	5.2E-3	2.4E-3
6	2.0E-5	3.0E-5	2.4E-2	7.0E-3
7	5.0E-5	5.0E-5	5.2E-3	1.0E-2
8	6.0E-5	5.0E-5	8.5E-3	1.5E-2
9	8.0E-5	6.0E-5	6.0E-3	1.3E-2
10	8.0E-5	5.0E-5	6.5E-3	1.1E-2
11	1.0E-4	2.0E-4	1.6E-2	5.4E-2
12	5.7E-4	2.8E-4	1.6E-2	9.4E-2
13	7.0E-4	1.3E-3	2.1E-2	7.0E-2
14	1.8E-3	2.6E-2	2.8E-2	7.6E-2
15	1.9E-3	1.5E-3	2.8E-2	2.0E-2
16	1.6E-3	1.8E-3	1.4E-2	2.6E-2
17	1.7E-3	2.3E-3	3.3E-2	1.4E-2
18	1.9E-3	1.7E-3	1.0E-2	2.6E-2
19	2.4E-3	2.3E-3	1.0E-2	3.5E-2
20	2.1E-3	3.6E-3	2.9E-2	2.9E-2
21	4.2E-3	5.5E-3	*	*

*No reading at max luminance.

L6

FILTER	10' LEFT	10' RIGHT	2' LEFT	2' RIGHT
1	7.5E-4	1.9E-3	5.1E-3	*
2	6.2E-4	1.2E-3	1.7E-2	1.9E-2
3	1.7E-3	7.5E-4	5.2E-3	2.6E-2
4	2.5E-4	2.3E-4	5.1E-3	7.2E-3
5	1.5E-3	8.5E-4	3.6E-2	6.0E-3
6	1.3E-3	1.7E-4	1.3E-2	9.0E-3
7	4.0E-4	3.3E-4	6.4E-2	6.0E-2
8	2.8E-4	4.0E-4	7.0E-3	5.5E-3
9	1.1E-3	1.1E-3	7.5E-3	1.6E-2
10	5.5E-4	5.5E-4	6.0E-3	6.0E-3
11	1.3E-3	7.5E-4	2.0E-2	1.6E-2
12	1.1E-3	9.5E-4	4.0E-3	8.0E-4
13	3.4E-3	1.8E-3	4.5E-3	1.9E-2
14	2.0E-3	3.4E-3	7.5E-3	7.0E-3
15	2.3E-3	1.7E-3	4.0E-3	6.5E-3
16	1.7E-3	1.4E-3	4.0E-3	3.0E-3
17	1.5E-3	1.4E-3	3.0E-3	4.0E-3
18	1.6E-3	1.4E-3	5.0E-3	4.0E-3
19	2.3E-3	2.4E-3	9.5E-3	5.5E-3
20	2.8E-3	2.5E-3	9.0E-3	8.0E-3
21	3.9E-3	3.1E-3	1.1E-2	8.0E-3

*No reading at max luminance.

L7

1	2.5E-4	1.9E-4	1.7E-3	2.2E-3
2	1.4E-4	1.1E-4	2.2E-3	2.2E-3
3	1.0E-4	1.5E-4	3.9E-3	4.0E-3
4	2.8E-4	2.6E-4	8.5E-3	6.6E-3
5	5.1E-4	4.4E-4	1.2E-2	9.5E-3
6	4.5E-4	3.3E-4	1.3E-2	1.2E-2
7	3.1E-4	4.5E-4	2.1E-2	1.4E-2
8	2.2E-4	2.7E-4	1.2E-2	8.5E-3
9	6.2E-4	6.2E-4	1.7E-2	1.3E-2
10	3.8E-4	2.0E-4	2.5E-2	2.2E-2
11	5.4E-4	4.6E-4	2.0E-2	2.7E-2
12	5.5E-4	3.2E-4	8.7E-2	4.9E-2
13	1.1E-3	5.0E-4	1.8E-2	1.3E-2
14	2.1E-3	1.1E-3	1.0E-2	9.0E-3
15	1.2E-3	9.7E-4	6.5E-3	1.2E-2
16	1.2E-3	1.1E-3	1.1E-2	9.5E-3
17	1.1E-3	1.1E-3	7.5E-3	8.0E-3
18	1.5E-3	1.0E-3	6.0E-3	7.0E-3
19	1.6E-3	1.2E-3	7.5E-3	8.5E-3
20	1.8E-3	1.9E-3	7.0E-3	8.5E-3
21	1.8E-3	1.7E-3	1.5E-2	1.4E-2

C1

FILTER	10' LEFT	10' RIGHT	2' LEFT	2' RIGHT
1	N		*	*
2	O		*	*
3			1.5E-2	1.6E-2
4	T		3.6E-2	1.4E-2
5	E		3.5E-2	4.6E-2
6	S		3.8E-2	3.1E-2
7	T		4.6E-2	2.6E-2
8			1.2E-2	2.8E-2
9	A		1.8E-2	1.9E-2
10	D		4.5E-2	3.4E-2
11	M		2.9E-2	3.2E-2
12	I		1.8E-2	1.2E-2
13	N		4.0E-2	5.5E-2
14	I		1.6E-2	3.3E-2
15	S		2.1E-2	1.8E-2
16	T		1.5E-2	1.6E-2
17	E		2.8E-2	2.5E-2
18	R		4.5E-2	1.4E-2
19	E		2.0E-2	3.0E-2
20	D		2.2E-2	*
21			*	*

*No reading at max luminance.

C2

FILTER	10' LEFT	10' RIGHT	2' LEFT	2' RIGHT
1	5.0E-4	8.0E-4	N	
2	3.0E-4	5.0E-4	O	
3	1.5E-3	1.0E-3		
4	3.6E-3	4.5E-4	T	
5	3.3E-3	7.5E-4	E	
6	3.6E-3	1.1E-3	S	
7	2.0E-3	6.0E-4	T	
8	8.0E-4	3.3E-3		
9	6.0E-4	2.8E-3	A	
10	3.5E-3	2.7E-3	D	
11	4.5E-3	3.1E-3	M	
12	4.2E-3	5.7E-3	I	
13	7.5E-3	4.4E-3	N	
14	6.3E-3	7.3E-3	I	
15	3.7E-3	2.3E-3	S	
16	3.9E-3	4.6E-3	T	
17	2.8E-3	4.2E-3	E	
18	3.1E-3	4.8E-3	R	
19	3.8E-3	3.0E-3	E	
20	3.1E-3	6.4E-3	D	
21	5.4E-3	5.0E-3		

C3

FILTER	10' LEFT	10' RIGHT	2' LEFT	2' RIGHT
1	N		*	*
2	O		4.4E-2	4.8E-2
3			3.2E-2	3.6E-2
4	T		6.6E-2	2.3E-1
5	E		9.0E-2	6.5E-2
6	S		3.4E-2	1.9E-2
7	T		2.6E-2	1.4E-2
8			2.0E-2	2.2E-2
9	A		1.8E-2	2.5E-2
10	D		3.8E-2	2.0E-2
11	M		2.2E-2	1.9E-2
12	I		1.7E-2	1.0E-2
13	N		8.0E-3	8.0E-3
14	I		1.2E-2	8.0E-3
15	S		1.0E-2	8.0E-3
16	T		1.0E-2	8.0E-3
17	E		9.0E-3	8.0E-3
18	R		1.2E-2	7.0E-3
19	E		1.5E-2	1.5E-2
20	D		1.8E-2	1.9E-2
21			2.1E-2	1.8E-2

*No reading at max luminance.

C4

1	2.1E-3	2.1E-3	*	*
2	2.0E-3	2.7E-3	4.9E-2	2.6E-2
3	2.9E-3	2.2E-3	1.2E-1	5.0E-2
4	3.8E-3	3.1E-3	1.3E-1	4.7E-2
5	3.9E-3	3.6E-3	1.3E-1	6.2E-2
6	3.8E-3	3.2E-3	1.6E-1	4.7E-2
7	4.1E-3	2.4E-3	5.5E-2	4.0E-2
8	5.1E-3	2.9E-3	7.0E-2	3.6E-2
9	2.5E-3	4.5E-3	7.5E-2	4.5E-2
10	4.7E-3	2.1E-3	4.5E-2	2.2E-2
11	5.0E-3	2.1E-3	4.0E-2	3.2E-2
12	4.1E-3	2.8E-3	1.8E-2	1.7E-2
13	4.6E-3	2.6E-3	1.7E-2	2.1E-2
14	2.6E-3	2.0E-3	1.3E-2	1.4E-2
15	2.0E-3	1.6E-3	1.6E-2	8.0E-3
16	1.4E-3	1.2E-3	1.6E-2	1.4E-2
17	1.1E-3	1.2E-3	2.4E-2	1.6E-2
18	1.7E-3	1.8E-3	2.1E-2	1.9E-2
19	1.6E-3	3.0E-3	2.6E-2	2.6E-2
20	3.3E-3	2.3E-3	2.4E-2	3.7E-2
21	4.0E-3	3.8E-3	3.5E-2	3.5E-2

*No reading at max luminance.

C5

FILTER	10' LEFT	10' RIGHT	2' LEFT	2' RIGHT
1	1.3E-3	1.4E-3	1.1E-2	1.0E-2
2	1.3E-3	9.5E-4	2.2E-2	5.1E-2
3	2.2E-3	3.1E-3	6.1E-2	4.3E-2
4	2.5E-3	2.1E-3	6.0E-2	6.0E-2
5	3.3E-3	3.4E-3	6.3E-2	3.8E-2
6	4.1E-3	5.5E-3	6.9E-2	5.3E-2
7	4.6E-3	2.7E-3	4.0E-2	3.1E-2
8	2.1E-3	2.4E-3	3.8E-2	3.0E-2
9	3.9E-3	2.8E-3	3.6E-2	3.0E-2
10	2.6E-3	4.5E-3	3.8E-2	2.2E-2
11	3.0E-3	2.5E-3	2.7E-2	3.5E-2
12	3.3E-3	2.3E-3	3.0E-2	3.3E-2
13	3.7E-3	3.4E-3	3.3E-2	3.1E-2
14	2.4E-3	1.9E-3	1.1E-2	2.4E-2
15	1.4E-3	1.6E-3	1.0E-2	1.2E-2
16	1.2E-3	1.5E-3	1.5E-2	1.0E-2
17	1.1E-3	1.6E-3	1.4E-2	1.2E-2
18	1.9E-3	1.8E-3	1.6E-2	1.0E-2
19	2.0E-3	1.5E-3	1.3E-2	2.1E-2
20	2.1E-3	1.9E-3	1.7E-2	3.1E-2
21	2.6E-3	2.6E-3	2.4E-2	2.8E-2

C6

FILTER	10' LEFT	10' RIGHT	2' LEFT	2' RIGHT
1	*	*	*	*
2	3.1E-3	3.8E-3	*	*
3	2.6E-3	6.1E-3	*	*
4	6.6E-3	9.2E-3	3.2E-1	3.1E-1
5	5.9E-3	6.5E-3	3.6E-1	3.9E-1
6	6.0E-3	1.4E-2	6.2E-1	5.2E-1
7	8.3E-3	1.0E-2	2.2E-1	6.2E-1
8	4.5E-3	6.7E-3	9.4E-1	6.4E-1
9	8.0E-3	1.3E-2	1.1E-1	2.0
10	5.5E-3	1.1E-2	5.5E-2	2.1E-1
11	3.5E-3	5.0E-3	5.0E-2	1.7E-1
12	7.0E-3	4.5E-3	8.5E-2	1.3E-1
13	2.5E-3	4.5E-3	3.5E-2	9.7E-2
14	4.0E-3	5.2E-3	2.5E-2	4.4E-2
15	3.3E-3	2.2E-3	2.8E-2	3.0E-2
16	2.5E-3	3.1E-3	1.6E-2	3.4E-2
17	1.6E-3	1.8E-3	1.7E-2	3.1E-2
18	2.6E-3	2.0E-3	1.9E-2	2.4E-2
19	2.0E-3	2.5E-3	3.0E-2	2.2E-2
20	2.4E-3	3.4E-3	2.3E-2	3.1E-2
21	2.8E-3	3.8E-3	*	*

*No reading at max luminance.

C7

FILTER	10' LEFT	10' RIGHT	2' LEFT	2' RIGHT
1	N		*	1.5E-2
2	O		6.4E-2	4.2E-2
3			9.4E-2	1.3E-1
4	T		1.3E-1	1.7E-1
5	E		1.7E-1	1.1E-1
6	S		1.5E-1	6.0E-2
7	T		1.7E-1	5.0E-2
8			2.5E-1	4.7E-2
9	A		1.0E-1	3.7E-2
10	D		8.0E-2	4.2E-2
11	M		4.8E-2	2.6E-2
12	I		2.6E-2	3.1E-2
13	N		4.4E-2	2.6E-2
14	I		2.7E-2	1.6E-2
15	S		2.7E-2	1.4E-2
16	T		2.6E-2	9.0E-3
17	E		1.6E-2	1.5E-2
18	R		1.9E-2	1.5E-2
19	E		2.1E-2	2.2E-2
20	D		2.8E-2	2.3E-2
21			3.6E-2	2.9E-2

*No reading at max luminance.

C8

FILTER	10' LEFT	10' RIGHT	2' LEFT	2' RIGHT
1	1.1E-4	7.5E-4	1.8E-2	1.4E-2
2	1.5E-4	1.0E-4	3.9E-2	1.3E-2
3	1.1E-4	9.0E-5	1.3E-2	2.0E-2
4	2.5E-4	2.5E-4	7.0E-3	1.3E-2
5	7.5E-4	4.0E-5	1.3E-2	2.7E-2
6	3.0E-5	5.0E-5	1.0E-2	4.0E-2
7	2.0E-5	1.3E-4	9.0E-3	1.3E-2
8	9.0E-5	3.4E-4	7.5E-3	1.3E-2
9	8.0E-5	1.9E-4	5.5E-3	1.2E-2
10	1.1E-4	6.1E-4	5.0E-3	8.0E-3
11	3.2E-4	5.2E-4	6.0E-3	7.5E-3
12	4.0E-4	7.8E-4	6.5E-3	6.5E-3
13	8.0E-4	7.2E-4	6.5E-3	7.5E-3
14	3.5E-4	6.0E-4	5.5E-3	5.0E-3
15	4.5E-4	4.7E-4	9.0E-3	4.0E-3
16	5.0E-4	4.2E-4	4.0E-3	3.0E-3
17	5.0E-4	4.8E-4	6.0E-3	4.0E-3
18	6.8E-4	5.5E-4	7.5E-3	5.5E-3
19	8.6E-4	1.2E-3	1.1E-2	5.5E-3
20	1.3E-3	1.2E-3	1.3E-2	9.0E-3
21	1.8E-3	1.5E-3	1.3E-2	1.0E-2

C9

FILTER	10' LEFT	10' RIGHT	2' LEFT	2' RIGHT
1	N		*	*
2	O		*	*
3			*	*
4	T		*	*
5	E		3.5E-1	*
6	S		4.8E-1	4.8E-1
7	T		1.4E-1	2.8E-1
8			1.4E-1	2.2E-1
9	A		9.0E-2	1.2E-1
10	D		1.1E-1	1.8E-1
11	M		1.6E-1	4.8E-1
12	I		7.1E-2	8.0E-2
13	N		4.2E-2	7.3E-2
14	I		2.9E-2	6.5E-2
15	S		2.5E-2	3.4E-2
16	T		2.6E-2	2.9E-2
17	E		4.3E-2	5.0E-2
18	R		3.4E-2	6.5E-2
19	E		3.2E-2	4.5E-2
20	D		*	*
21			*	*

*No reading at max luminance.

C10

FILTER	10' LEFT	10' RIGHT	2' LEFT	2' RIGHT
1	N		*	*
2	O		*	*
3			*	*
4	T		3.5E-2	6.0E-2
5	E		2.9E-1	1.0E-1
6	S		1.2E-1	6.0E-2
7	T		1.1E-1	4.5E-2
8			1.9E-1	2.0E-2
9	A		7.0E-2	2.5E-2
10	D		3.0E-2	3.5E-2
11	M		3.5E-2	2.5E-2
12	I		3.5E-2	3.5E-2
13	N		3.0E-2	1.2E-1
14	I		4.5E-2	1.0E-1
15	S		3.5E-2	4.0E-2
16	T		2.5E-2	4.5E-2
17	E		3.0E-2	6.0E-2
18	R		3.5E-2	7.5E-2
19	E		5.5E-2	1.6E-2
20	D		7.5E-2	*
21			*	*

*No reading at max luminance.

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