Technical Memorandum 4-77

A HUMAN FACTORS EVALUATION OF A VERTICAL-SCALE INSTRUMENT DISPLAY SYSTEM FOR THE OV-1D AIRCRAFT

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January 1977
AMCMS Code 622209.12.47600

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Aberdeen Proving Ground, Maryland

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	Technical Memorandum 4-77
2. GOVT ACCESSION NO.	
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle)	A HUMAN FACTORS EVALUATION OF A VERTICAL-SCALE INSTRUMENT DISPLAY SYSTEM FOR THE OV-1D AIRCRAFT
5. TYPE OF REPORT & PERIOD COVERED	Final rept.
6. PERFORMING ORG. REPORT NUMBER	HEL-TM-4-77
7. AUTHOR(s)	Harry R. Stowell Alan M. Poston
8. CONTRACT OR GRANT NUMBER(s)	AMCMS Code 622209.12.47600
9. PERFORMING ORGANIZATION NAME AND ADDRESS	U. S. Army Human Engineering Laboratory Aberdeen Proving Ground, Maryland 21005
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS	
11. CONTROLLING OFFICE NAME AND ADDRESS	
12. REPORT DATE	Jan 1977
13. NUMBER OF PAGES	49 (52 p.)
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	
15. SECURITY CLASS. (of this report)	Unclassified
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE	

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Aircraft
Instrument Display System
Vertical Scale
OV-1D Aircraft
Human Factors Engineering

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Because of the increased importance of conserving aircraft instrument-panel space, vertical-scale instrument displays are being given greater consideration. In an effort to identify any potential problems associated with vertical-scale instrument displays, a human-factors evaluation was performed on the production prototype of the vertical-scale instrument display for the OV-1D. Some of the factors considered in the investigation include light distribution, spectral analysis, impact on dark adaptation, high-ambient conditions, and night-vision-goggle compatibility. Recommendations have been made with respect to the light distribution and marking sizes.

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CONTENTS

TABLES

A HUMAN FACTORS EVALUATION OF A VERTICAL-SCALE INSTRUMENT DISPLAY SYSTEM FOR THE OV-1D AIRCRAFT

INTRODUCTION

Military aviation is giving increasing recognition to display systems using vertical-scale instruments. Vertical-scale displays are being considered as replacements for the round dial because they can be arranged for faster reading with greater accuracy, and in less space.

Yet vertical-scale instruments are not without their drawbacks. Some vertical-scale displays have posed reliability problems. There have also been difficulties in designing suitable lighting systems for these displays. In addition, there are a variety of vertical-scale designs, including moving scales with stationary indicators, moving indicators with stationary scales, stationary scales with moving-tape indicators, and stationary scales with light-emitting-diode (LED) indicators which look like moving-tape indicators.

At the request of the U. S. Army Aviation Systems Command (AVSCOM), St. Louis, MO, the U. S. Army Human Engineering Laboratory (HEL) conducted a human-factors evaluation of the vertical-scale-instrument display system that is the production prototype for the OV-1D aircraft. The objectives of the evaluation were determining whether the prototype display required modifications, and determining whether this type of display system is suitable for other aircraft besides the OV-1D.

SYSTEM DESCRIPTION

The system must be described to show how it functioned and what measurements were possible. The largest part of the panel, containing the legends, numerals, and graduations, is edge-illuminated with instrument-panel-lighting (IPL) red. A rheostat on the test panel varies lighting intensity over its entire range by varying voltage from 0 to 5 VAC. There are test points for measuring the voltage applied to the panel.

Fiber optics carry light to the indicator scales. Various segments of the display are color coded by placing colored filters over the fiber optics. The bottom segment is always blue; the other segments are coded amber, green, or red, as applicable. Switches on the test-control panel can select any operating range on each individual scale. A rheostat on the lower right-hand part of the panel controls the brightness of the indicator lights. A photocell, positioned in the upper portion of the panel between the Prop RPM and N_1 Speed panels, acts as an automatic gain control, increasing indicator brightness in brighter ambient light. There are no test points to measure the voltage applied to the indicator scales. Indicator brightness was usually adjusted subjectively so it seemed compatible with the panel lighting.

An amber LED digital display is provided for the Torque, Prop RPM, N_1 Speed, EGT, and Amps panels. These digital readouts display, in digits, the same value shown on the indicator scale. The same circuitry that controls the indicator scales also controls the brightness of the LED's. There is a switch which can turn off the digits, but there are no test points for measuring voltage.

LIGHT DISTRIBUTION

In determining whether a display is adequate for use in low light levels and with night-vision goggles, uniform light distribution is a prime consideration. An uneven light distribution forces the pilot to either brighten the panel illumination to compensate for poorly illuminated areas, or dim the panel illumination to compensate for bright spots. In the first case, the overall panel illumination is so bright that it produces unwanted light flux in the cockpit. In the second case, the panel illumination is so dim that it makes portions of the display unreadable.

Unevenly lighted indicator scales can cause critical errors in assessing the aircraft's status. An unevenly lighted indicator segment might seem to be unlit, when it is really lit but very dim. If this very dim segment happens to be the first segment of a new operating range, the pilot will believe that one of the aircraft systems is in a different state than it actually is. This situation could become critical when the status changes from one operating range to another. For example, if a scale has been indicating in the green (normal) range, and if the first red or amber segment comes on but appears to be unlit, the pilot will see only the last green segment, and he will believe the system is still within normal limits.

This study measured light distribution by the ratio of the standard deviation (SD) to the mean value ($\bar{X}$). The individual photometric measurements of the panel, indicator lights, and the digital readouts are shown in Appendix A (Tables 1A through 10A). Figure 1 shows the relative positions of components on the display. Table 1 gives the computed values of the standard deviation, mean, and the light-distribution ratio.

TABLE 1

Photometric Measurements (fL): Standard Deviation and Mean Values

	SD	X	SD/X
Red–IPL	0.115	0.288	0.399
Red–Indicator Scale	0.962	1.471	0.654
Amber–Indicator Scale	1.350	2.096	0.644
Green–Indicator Scale	0.464	0.823	0.564
Blue–Indicator Scale	0.231	0.499	0.463
Amber–Digital Readout	3.134	6.426	0.488

HEL has not fully investigated the state-of-the-art associated with lighting this type of panel, but it seems reasonable to expect that these ratios can be improved. HEL has recommended that military specifications for aircraft lighting require controlling the light distribution for integrally illuminated instruments so that $SD/\bar{X}$ is 0.25 or less; light distribution on panels should be improved so it also meets this requirement. The unretouched photographs in Figures 2 and 3 illustrate the uneven light distribution on the IPL panel, the indicator scales, and the digital readouts.

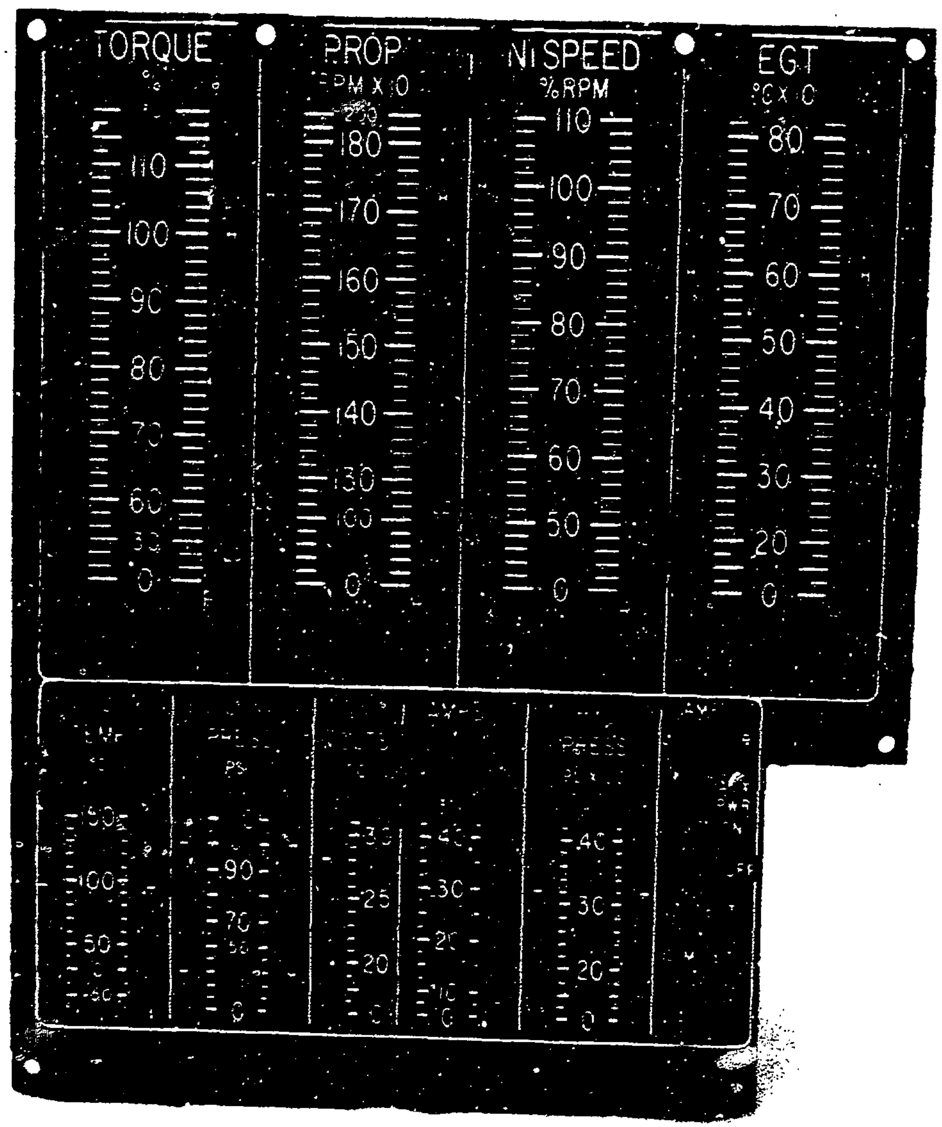

Figure 1. Vertical-scale instrument display.

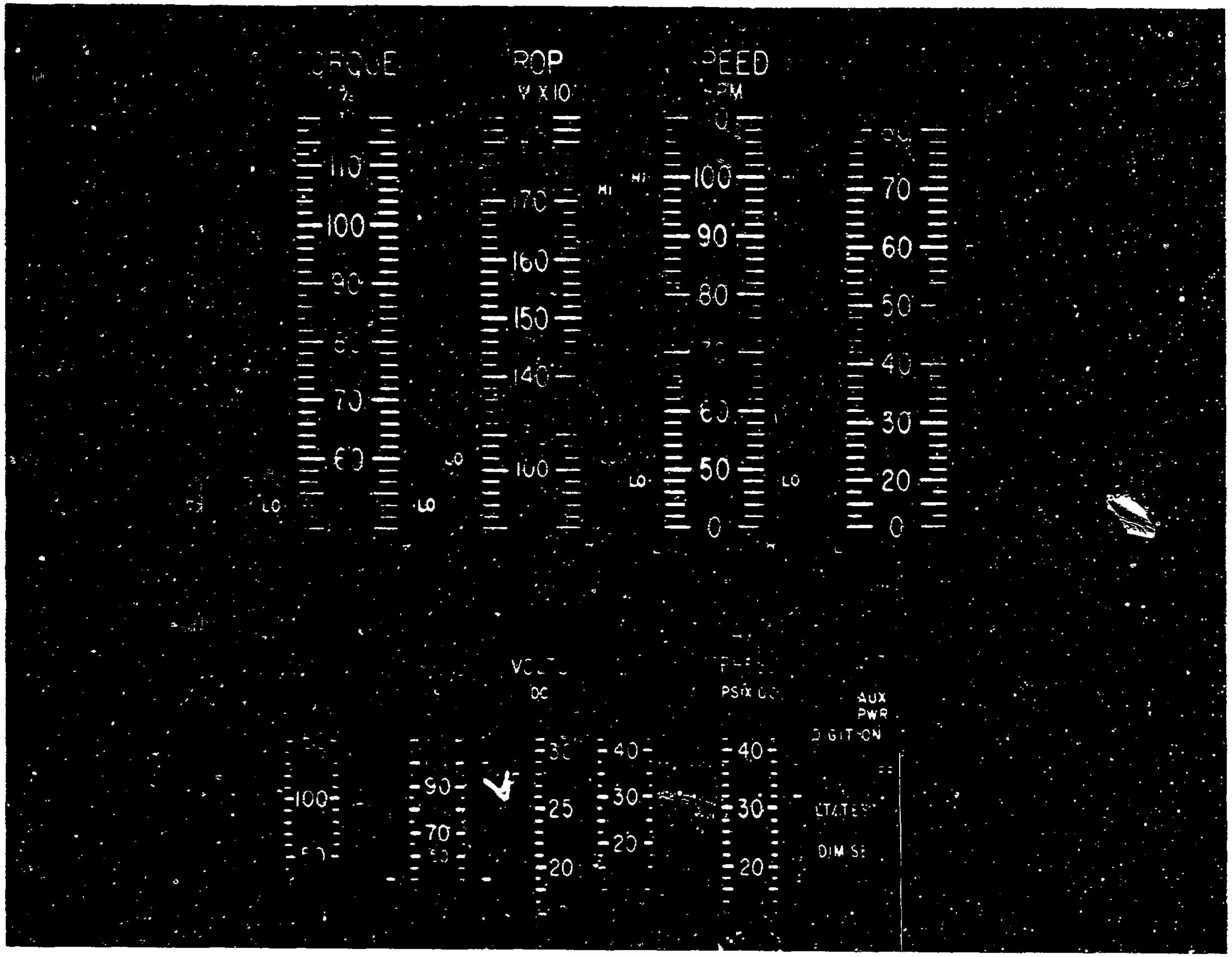

Figure 2. Light distribution of IPL lighting.

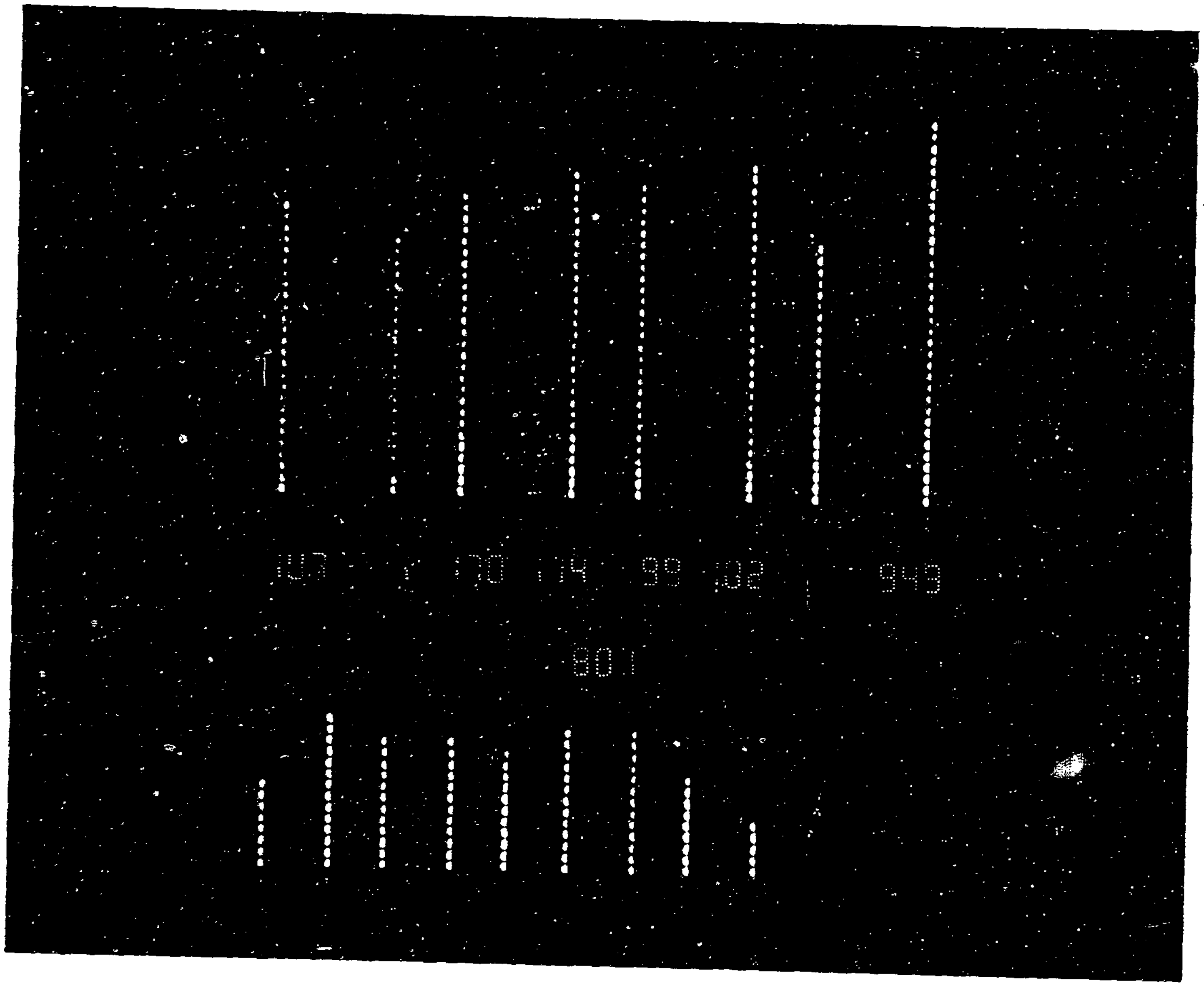

Figure 3. Light distribution of indicator scale and digital readout.

SPECTRAL ANALYSIS

Some readers may want to assess the spectral characteristics of the displays, to see whether changing light intensities cause any color shifts. Appendix B (Figures 1B through 12B) gives both photopically and scotopically corrected spectral luminance curves for each color. Three levels of brightness were used. The high intensity was the maximum brightness setting, with a light spot shining on the photocell, so the indicators were at their highest brightness. The medium level was the maximum brightness setting, but with the photocell exposed to dark ambient illumination. The low level was adjusted to a brightness similar to the instrument lighting used in night operations. There were only two intensity levels for the IPL red lighting. The high level was maximum brightness (5 VAC), the low level (2.67 VAC), representative of night flying, was the average level selected by different subjects before these measurements were made.

The shift of the total integrated lighting on the panel is more important than shifts of individual colors. Figures 13B through 16B (Appendix B) show the spectral luminance curves of the integrated panel lighting at two light intensities. The high level was with the IPL set at 5 VAC, and the indicator lights and digital readouts set for comparable light levels. The low level was with the IPL set at 2.67 VAC, and the indicator lights and digital readouts set for similar light levels. In either case, the spectral distribution was plotted first for the IPL alone, then for the IPL and the indicator lights, and finally for the IPL, indicator lights, and the digital readouts.

The digital readouts (LED's) are controlled by the same circuitry that controls the indicators. When the indicator luminance is adjusted for viewing with night-vision goggles, the digital readouts are not legible. But increasing the luminance so the digital readouts are legible makes the indicators too bright for reading with night-vision goggles. Either the luminances of the digital readouts and the indicators must be balanced so they are comparable, or there must be separate light-intensity controls.

The integrated luminance curves (Figures 13B through 16B) show a very slight color shift when intensity level changes, even though there was no shift between IPL alone, and IPL plus indicator scale plus digital readouts. The photopic curve shifted from approximately 570 nm (low level) to 580 nm (high level). The scotopic curve shifted from approximately 500 nm to 510 nm. These color shifts are relatively insignificant, and their effects on night vision should be very small.

IMPACT ON DARK ADAPTATION

To determine how the display affects dark adaptation, subjects' dark adaptation was measured after exposure to various levels of panel lighting. The display was incorporated into an instrument-panel mock-up, and each subject was seated with his eyes 28 inches from the display (Figure 4). After 30 minutes of dark adaptation, each subject viewed an adaptometer positioned 30 inches away from him and 20 degrees right of the instrument panel's centerline. Dark adaptation was measured as the amount of lamp illumination required for the subject to detect the light.

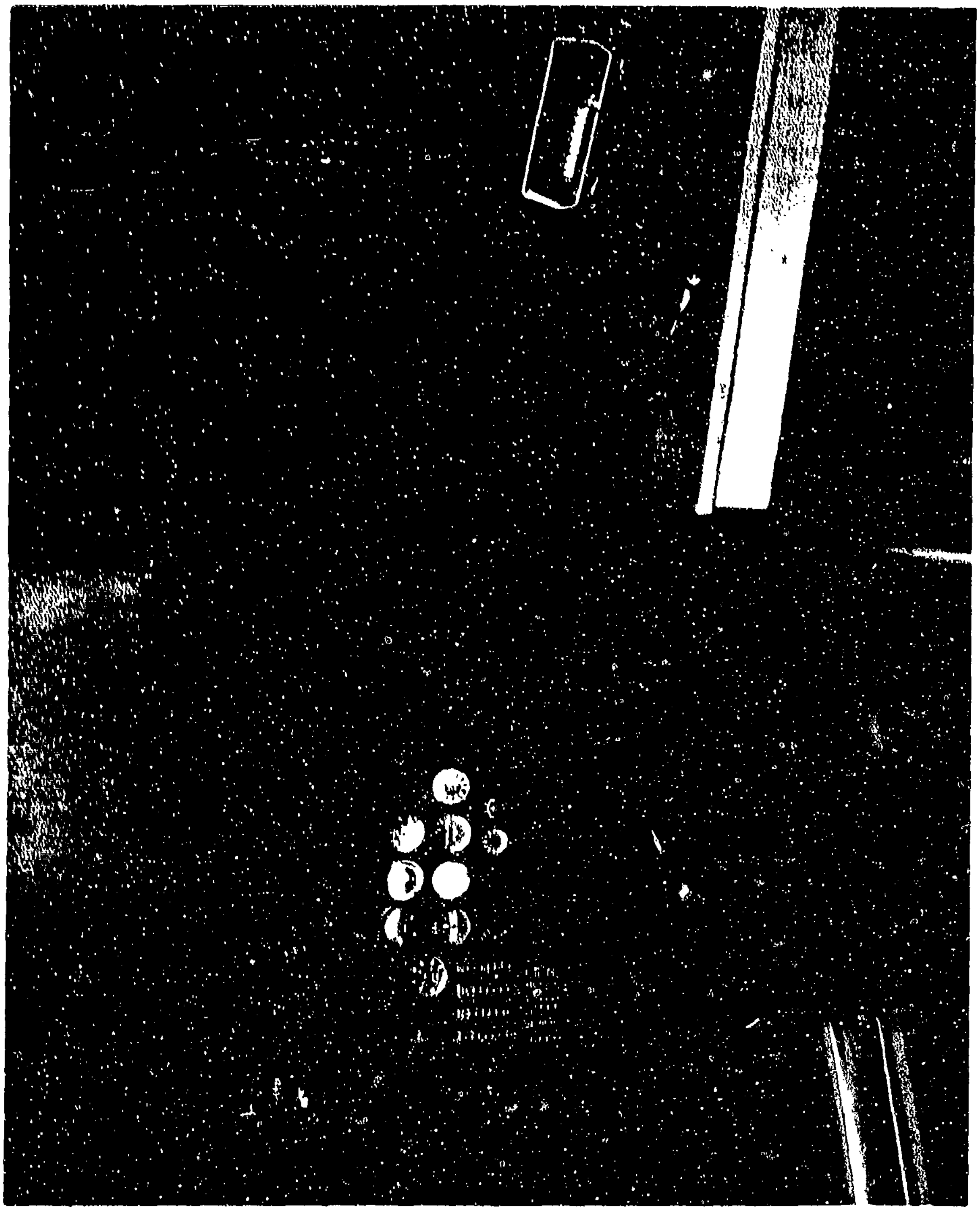

Figure 4. Dark-adaptation apparatus.

Subjects viewed the adaptometer under three conditions of display illumination. The first condition was with the display turned off (dark room conditions). The second condition was with the IPL set at 2.67 VAC (a level established as suitable for night flight), and with indicator scales and digital readouts set comparable to the IPL panel. The third condition was with the IPL set at 2.67 VAC, and with the indicator scales and digital readouts set to maximum brightness and the photocell exposed to dark ambient conditions. In all three conditions, the ambient illumination approached 1.0×10^{-7} foot-candles.

When the subject could see the adaptometer light, the lamp voltage was recorded; later, a calibration curve (Figure 5) was used to convert this voltage to a luminance value. Figure 6 is an enlarged view of the lower portion of the calibration curve.

The measured voltage levels (Table 2) are the average of several trials for each subject under each condition. In the second condition, the illuminance at the subject's eye was 1.6×10^{-4} foot-candles; in the third condition, it was 1.9×10^{-3} foot-candles.

The results indicated that increased light flux produced little or no degradation of dark adaptation. The average voltage levels of 0.653 and 0.656 volts correspond to an adaptometer-lamp luminance of 2.25×10^{-5} foot-Lamberts, and 0.623 volts equates to 1.8×10^{-6} foot-Lamberts. These findings were consistent, regardless of the order of the test conditions.

TABLE 2

Dark-Adaptation Levels (Volts)

Subject	Condition No. 1	Condition No. 2	Condition No. 3
1	0.68	0.62	0.64
2	0.70	0.64	0.64
3	0.73	0.65	0.63
4	0.61	0.59	0.64
5	0.68	0.67	0.71
6	0.61	0.61	0.65
7	0.63	0.59	0.62
8	0.61	0.61	0.69
Mean	0.656	0.623	0.653

Condition No. 1: All display lights off

Condition No. 2: IPL = 2.67 VAC (a level found to be compatible with night flight); indicator scales and digital readouts compatible with the IPL.

Condition No. 3: IPL = 2.67 VAC; indicator scales and digital readouts at maximum for dark ambient conditions.

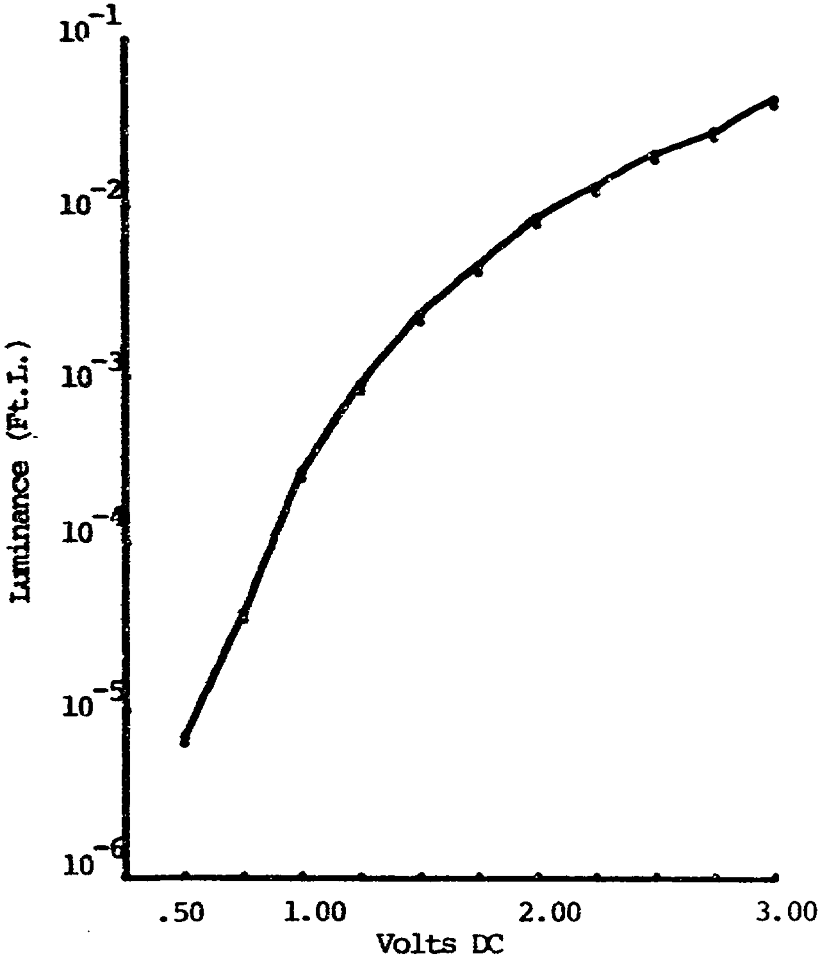

Figure 5. Luminance versus voltage for adaptometer lamp.

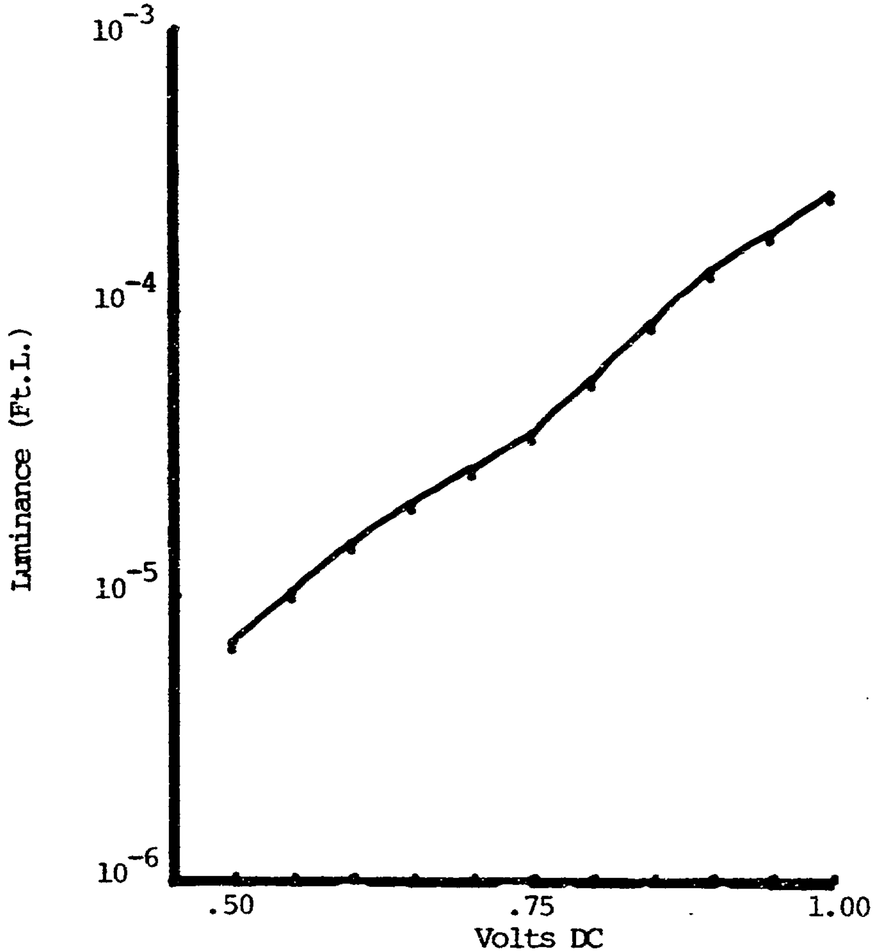

Figure 6. Luminance versus voltage for adaptometer lamp—expanded scale.

Two observations during these trials seem worthy of mention. First, the light levels were bright enough to activate the cones, because the subjects were able to discriminate colors. Second, and more important, the subjects were exposed not to individual colors, but to the total integrated light flux. Hence the total light flux reaching the subject's eye may be more significant than the color components that comprise it.

PERFORMANCE UNDER HIGH AMBIENT LIGHT

An additional consideration in evaluating vertical-scale instruments is their performance under high-ambient-light conditions. To determine whether the vertical scales would "wash out" in bright sunshine, photometric measurements of the instruments were taken outdoors (Table 3).

The measurements were taken at several different segments of each color, as well as from the digits of the digital readouts. The measurements were made in the early afternoon, with clear sky, and visibility estimated at more than 10 miles. The ambient light at the instruments measured 7980 foot-candles.

The measurements in Table 3 were made in pairs: first, a measurement of the colored part of the indicator scale, then a measurement of the dark portion of the scale next to the lighted segment. Table 3 also shows the contrast ratio. The contrast ratio, defined as in paragraph 3.18 of MIL-STD-1472B (1), is computed from the formula $CR = (L_1 - L_2)/L_1$, where L_1 is the higher luminance and L_2 is the lower luminance.

Paragraphs 5.2.2.1.12 and 5.2.3.1.8 of MIL-STD-1472B require a luminance contrast of at least 0.50 (50 percent) for indicator displays. The computed contrast ratios show that the colored indicator scales do exceed this minimum value and are acceptable. Thus the measurements confirm the opinions formed during a visual examination.

HUMAN FACTORS ANALYSIS

Night-Vision-Goggle Compatibility

Because of night-vision goggles' increased importance in low-level or nap-of-the-earth night flying, their compatibility with the instrument display system is of prime concern. It has been established that the red-IPL scale luminance at approximately 0.92 VAC ($1.5x10^{-5}$ fL.) is compatible with the AN/PVS-5 night-vision goggles. This finding is consistent with the previous one in HEL Technical Memorandum 26-76. However, luminance must be distributed uniformly for good legibility at low-level settings.

When the indicator lights are adjusted to a level which is compatible with the IPL, the light distribution is so grossly uneven that some of the segments are not even visible. This degradation could be critical, because the crew will read operating ranges erroneously. Another factor to consider is that, with night-vision goggles, the indicator scales cannot be color coded, so there must be some other method to display operating limits.

TABLE 3

Photometric Measurements and Contrast Ratios
Under High-Ambient Conditions (fL.)

	Indicator	Background	Contrast Ratio (%)
Green:	355.0	101.5	71.4
	300.0	94.5	68.5
	395.0	99.0	74.9
	360.0	105.0	70.8
Red:	325.0	121.0	62.8
	460.0	114.0	75.2
	255.0	120.0	52.9
	328.0	125.0	61.9
	290.0	123.0	57.6
	280.0	115.0	58.9
Amber:	515.0	79.0	84.7
	800.0	97.0	87.9
	435.0	78.0	82.1
	740.0	77.0	89.6
Blue:	156.0	72.0	53.8
	170.0	76.0	55.3
	267.0	69.0	74.2
	140.0	84.0	40.0
Amber (digits)	780.0	97.0	87.6
	565.0	75.0	86.7
	800.0	50.0	93.8
	570.0	60.0	89.5

The luminance levels of the digital readouts and the indicator scales differ appreciably (Tables 1A through 10A). The difference in luminous intensity is more apparent at low luminance settings. Separate controls may be required to match these luminance levels; a single control did not give equal luminance values.

Blue Indicator-Scale Lights

The bottom indicator-scale light is blue. However, regardless of whether the panel is viewed in a night-flight configuration or a daytime configuration, the blue light is not visible. This may arise from the construction of the indicator, since it appears that a blue filter has been placed over the red or amber filter which would normally cover that light. Because the blue light is difficult to see and the purpose for using it is unclear, it is recommended that the blue color be eliminated unless there is a strong justification for retaining it.

Markings

A large amount of the light-emitting area is devoted to markings (graduations, numerals, and legends). This large light-emitting area produces an unnecessarily high light flux in the cockpit. The sizes of these letters, numerals, and graduations can be reduced without sacrificing legibility. HEL has recommended that military specifications use findings from previous work to standardize and improve instrument markings.

The number of graduations can also be reduced, especially on the larger instruments. Whenever possible, crew members will determine operating conditions from the color coding, rather than by reading numbers and graduations. In any event, there is a digital readout and, if it should fail, crew members can still interpolate scale readings fairly accurately. Therefore it is recommended that the graduation intervals on the larger instruments–Torque, Prop RPM, N_1 Speed, and EGT–should be changed from two units to five units.

The combination of eliminating unnecessary graduations and reducing the size of the remaining markings will greatly reduce the amount of light flux in the cockpit. When pilots use night-vision goggles, lower light flux in the cockpit means better visibility of the external scene. Internal legibility will also increase, because smaller markings will have clearly defined edges; larger markings are undesirable because, at the same voltage, they produce a spillover or wash-out effect, reduce contrast, and degrade the definition of characters.

Appendix C summarizes HEL's recommendations for modifying the present specifications for markings. While these values are intended for circular instruments, they also appear applicable to vertical-scale instruments.

Digital Readouts and Indicator Scales

Some of the individual luminance curves (Figures 1B through 12B) show significant color shifts. While one might mistakenly assume they arose from adjusting the intensity levels, these color shifts are really mostly due to variations in the color filters. Although measurements were made on points with the same chromaticity, they were not necessarily the same points. This indicates that the uniformity of the display filters should be controlled more precisely.

When the indicator-scale brightness is adjusted so it is compatible with the panel lighting at low levels, it becomes difficult to distinguish the red and amber portions. In a quick glance, it would be very easy to confuse the two regions. Perhaps different chromaticity values should be specified to make these colors more discriminable.

The location for the display panel should be selected very carefully. For best efficiency, a pilot should view digital readouts from directly in front of them, or within 15 degrees of it. As the observer moves off-axis, the display loses legibility and finally becomes unreadable. This effect must be considered when locating the display panel in the cockpit.

CONCLUSIONS

The human-factors analysis of the production prototype of the OV-1D aircraft's vertical-scale-instrument display system indicates these conclusions:

- Light distribution from the instrument-panel lighting (IPL), indicator scales, and digital readouts is too uneven. HEL recommends that the lighting specifications call for a $SD/\overline{X}$ that is less than 0.25.

- Adjusting the voltages to the vertical-scale-instrument display causes only small color shifts, which should not create any problems.

- Different colors of light in the vertical-scale-instrument display have little or no effect on dark adaptation at low-level luminance settings.

- The indicators and digital readouts in the cockpit are legible under bright ambient conditions (sunlight).

- Marking sizes should be reduced to minimize unnecessary light flux in the cockpit (see Appendix C).

- The luminance adjustment for the digital readouts and the indicator scales should be improved so both kinds of displays have comparable luminance at low-level settings. It may prove necessary to provide separate controls.

- Color coding should be improved to make the red and amber more discriminable at low-level settings. It may be necessary to select colors that contrast more than the present ones.

• The digital readouts may require a separate luminance adjustment to make them compatible with the night-vision goggles, AN/PVS-5, at low luminance settings (1.5×10^{-4} fL.).

• The display panel should be placed so the viewing axis of the digital readouts is within 15 degrees of the pilot's line of sight. This important limitation must be considered in selecting display locations in the cockpit.

REFERENCES

1. Department of Defense. Human engineering design criteria for military systems, equipment and facilities. MIL-STD-1472B, Washington, DC, 31 December 1974.

2. Stowell, H. R. An investigation of cockpit lighting for compatibility with use of night-vision goggles, AN/PVS-5. Technical Memorandum 26-76, U. S. Army Human Engineering Laboratory, Aberdeen Proving Ground, MD, July 1976.

APPENDIX A

PHOTOMETRIC DATA

TABLE 1A

Photometric Measurements of Torque Panel

Legend	Luminance (fL.)	Numerals	Luminance (fL.)
T	0.23	0	0.20
O	0.24	3 in 30	0.22
R	0.23	0 in 30	0.21
Q	0.23	6 in 60	0.42
U	0.23	0 in 60	0.40
E	0.23	7 in 70	0.34
%	0.24	0 in 70	0.38
R	0.27	8 in 80	0.22
HI	0.10	0 in 80	0.22
LO	0.87	9 in 90	0.24
L	0.25	0 in 90	0.27
HI	0.09	1 in 100	0.42
LO	0.52	0 in 100	0.53
		1 in 110	0.36
		0 in 110	0.37
		1 in 130	0.26
		0 in 130	0.24

TABLE 1A (Continued)

Photometric Measurements of Torque Panel

Graduations:	Luminance (fL.) Left	Right	Indicator Scale:	Luminance (fL.) Left	Right
0	0.21	0.20	Red	0.68	
30	0.25	0.26		0.31	
60	0.38	0.39		0.40	
70	0.38	0.38		0.50	
80	0.22	0.27		1.2	
90	0.24	0.27		0.58	
100	0.41	0.53	Amber	1.1	
110	0.34	0.35		0.83	
130	0.29	0.22		1.0	
			Green	0.49	0.55
				0.77	0.49
Digits				0.87	0.34
2	6.0			0.58	0.51
1	9.0			0.62	0.41
3	6.9			0.62	0.37
6	5.7			0.43	0.53
				0.68	0.37
				0.58	0.38
			Amber	1.5	0.69
			Blue	0.41	0.16

TABLE 2A

Photometric Measurements of Prop RPM Panel

Legend	Luminance (fL.)	Numerals	Luminance (fL.)
P	0.18	0	0.15
R	0.22	1 in 100	0.32
O	0.29	0 in 100	0.31
P	0.43	1 in 130	0.22
R	0.16	0 in 130	0.23
P	0.18	1 in 140	0.20
M	0.21	0 in 140	0.21
X	0.26	1 in 150	0.41
1	0.30	0 in 150	0.41
O	0.32	1 in 160	0.29
R	0.28	0 in 160	0.32
HI	0.43	1 in 170	0.21
LO	0.55	0 in 170	0.23
L	0.23	1 in 180	0.17
HI	0.17	0 in 180	0.22
LO	0.45	2 in 200	0.21
		0 in 200	0.22

TABLE 2A (Continued)

Photometric Measurements of Prop RPM Panel

Graduations:	Luminance (fL.) Left	Right	Indicator Scales	Luminance (fL.) Left	Right
0	0.18	0.19	Red	0.47	0.08
100	0.30	0.26		0.41	0.22
130	0.25	0.18		0.73	0.03
140	0.22	0.18		1.0	0.07
150	0.41	0.39		0.42	0.13
160	0.31	0.27	Green	0.40	0.17
170	0.22	0.21		0.60	0.13
180	0.17	0.23		0.39	0.18
200	0.18	0.27		0.71	0.19
				0.25	0.38
				0.22	0.21
				0.16	0.15
Digits				0.27	0.19
2	4.3			0.30	0.16
1	6.5			0.17	0.21
4	6.5		Amber	0.36	0.95
3	9.2			0.34	0.68
4	8.1			0.19	0.37
1	9.4			0.26	1.1
				0.89	1.3
			Blue	0.25	0.25

TABLE 3A

Photometric Measurements of N_1 Speed Panel

Legends	Luminance (fL.)	Numerals	Luminance (fL.)
N	0.17	0	0.23
1	0.17	5 in 50	0.55
S	0.18	0 in 50	0.40
P	0.19	6 in 60	0.32
E	0.20	0 in 60	0.31
E	0.23	7 in 70	0.20
D	0.25	0 in 70	0.20
%	0.17	8 in 80	0.19
R	0.18	0 in 80	0.21
P	0.19	9 in 90	0.45
M	0.22	0 in 90	0.43
R	0.34	1 in 100	0.32
HI	0.24	0 in 100	0.29
LO	0.50	1 in 110	0.18
L	0.27	0 in 110	0.18
HI	0.39		
LO	0.53		

TABLE 3A (Continued)

Photometric Measurements of N_1 Speed Panel

Graduations	Luminance (fL.) Left	Right	Indicator Scale:	Luminance (fL.) Left	Right
0	0.27	0.22	Red	1.0	1.2
50	0.51	0.35		1.2	0.70
60	0.32	0.27		0.60	0.82
70	0.19	0.20		0.95	1.1
80	0.19	0.21	Amber	1.4	0.65
90	0.35	0.34	Green	0.93	0.75
100	0.29	0.27		0.52	0.61
110	0.17	0.19		0.57	0.62
				0.85	0.83
				0.80	0.42
				0.81	0.48
Digits				0.56	0.51
1	7.2			0.46	0.72
1	4.7			0.43	0.81
9	7.0			0.86	0.51
0	6.5			0.71	0.42
2	5.9			0.62	0.62
1	5.3		Amber	1.8	0.43
				2.2	1.3
				2.0	1.9
			Blue	0.22	0.29

TABLE 4A

Photometric Measurements of EGT Panel

Legends	Luminance (fL.)	Numerals	Luminance (fL.)
E	0.12	0	0.23
G	0.11	2 in 20	0.35
T	0.10	0 in 20	0.35
°C	0.15	3 in 30	0.27
X	0.13	0 in 30	0.41
1	0.13	4 in 40	0.19
O	0.12	0 in 40	0.21
R	0.08	5 in 50	0.21
HI	0.21	0 in 50	0.18
L	0.27	6 in 60	0.35
HI	0.12	0 in 60	0.31
		7 in 70	0.25
		0 in 70	0.27
		8 in 80	0.15
		0 in 80	0.17

TABLE 4A (Continued)

Photometric Measurements of EGT Panel

Graduations:	Luminance (fL.) Left	Right	Indicator Scale:	Luminance (fL.) Left	Right
0	0.28	0.19	Red	1.7	1.2
20	0.40	0.33		1.0	1.2
30	0.37	0.31		2.4	1.1
40	0.22	0.15		1.3	0.88
50	0.19	0.14		1.2	0.73
60	0.34	0.30		1.8	1.4
70	0.28	0.29		2.0	1.2
80	0.15	0.15	Amber	2.7	1.5
			Green	1.2	0.88
				1.2	0.63
Digits				0.72	0.65
8	4.8			0.93	0.87
5	4.3			0.56	0.51
9	5.2			0.75	0.49
9	5.9			0.81	0.89
6	5.8			1.5	0.55
2	6.0		Amber	1.8	1.8
				2.8	0.85
				2.7	2.4
				2.5	1.5
				3.3	2.1
			Blue	0.67	0.36

TABLE 5A

Photometric Measurement of Oil Temperature Panel

Legends	Luminance (fL.)	Numerals	Luminance (fL.)
O	0.15	5 in -50	0.14
I	0.17	0 in -50	0.12
L	0.17	0	0.20
T	0.19	5 in 50	0.32
E	0.20	0 in 50	0.26
M	0.18	1 in 100	0.52
P	0.17	0 in 100	0.43
O	0.20	1 in 150	0.28
C	0.23	0 in 150	0.23

TABLE 5A (Continued)

Photometric Measurements of Oil Temperature Panel

Graduations:	Luminance (fL.) Left	Right	Indicator Scale:	Luminance (fL.) Left	Right
-50	0.13	0.12	Red	1.9	4.0
0	0.21	0.16		3.7	2.8
50	0.32	0.25		2.5	1.9
70	0.68	0.39		1.5	3.3
100	0.52	0.44		2.5	3.9
120	0.28	0.29		1.3	2.9
150	0.20	0.20	Green	1.8	1.3
				1.1	1.1
				0.71	1.8
				1.0	1.7
				1.1	1.4
				1.2	1.1
			Blue	0.56	0.91

TABLE 6A

Photometric Measurements of Oil Pressure Panel

Legends	Luminance (fL.)	Numerals	Luminance (fL.)
O	0.26	0	0.17
I	0.26	5 in 50	0.27
L	0.27	0 in 50	0.29
P	0.21	7 in 70	0.44
R	0.21	0 in 70	0.46
E	0.23	9 in 90	0.44
S	0.22	0 in 90	0.41
S	0.23	1 in 100	0.30
P	0.27	0 in 100	0.26
S	0.26	1 in 110	0.24
I	0.22	0 in 110	0.23

TABLE 6A (Continued)

Photometric Measurements of Oil Pressure Panel

Graduations:	Luminance (fL.) Left	Right	Indicator Scale:	Luminance (fL.) Left	Right
0	0.15	0.13	Red	4.2	2.4
25	0.23	0.17		2.3	1.4
50	0.37	0.31	Green	1.4	0.79
70	0.65	0.45		1.4	1.0
80	0.71	0.46		1.5	1.3
90	0.51	0.39		1.5	0.98
100	0.35	0.29		1.1	1.1
110	0.22	0.22		1.0	1.2
				0.90	1.1
			Red	1.8	0.80
				1.8	1.2
			Blue	0.79	0.54

TABLE 7A

Photometric Measurements of Volts Panel

Legends	Luminance (fL.)	Numerals	Luminance (fL.)
V	0.40	0	0.21
O	0.28	20	0.36
L	0.28	25	0.34
T	0.27	30	0.25
S	0.25		
D	0.41		
C	0.37		

TABLE 7A (Continued)

Photometric Measurements of Volts Panel

Graduations	Luminance (fL.)	Indicator Scale	Luminance (fL.)
0	0.22	Red	1.3
10	0.31		0.80
20	0.51		1.4
22	0.62	Green	0.94
25	0.48		1.7
27	0.26		1.2
30	0.24		1.9
32	0.25	Amber	3.3
			1.9
			2.9
			3.5
		Red	1.8
			1.4
		Blue	0.51

TABLE 8A

Photometric Measurements of Amps Panel

Legends	Luminance (fL.)	Numerals	Luminance (fL.)
A	0.16	0	0.13
M	0.16	1 in 10	0.17
P	0.20	0 in 10	0.18
S	0.22	2 in 20	0.29
X	0.22	0 in 20	0.35
1	0.20	3 in 30	0.45
O	0.21	0 in 30	0.45
		4 in 40	0.27
		0 in 40	0.28

TABLE 8A (Continued)

Photometric Measurements of Amps Panel

Graduations:	Luminance (fL.) Left	Right	Indicator Scale:	Luminance (fL.) Left	Right
0	0.11	0.12	Red	2.2	1.4
10	0.17	0.19	Green	1.3	0.95
15	0.24	0.26		0.88	0.69
20	0.41	0.42		1.6	0.82
25	0.56	0.46		1.6	0.62
30	0.57	0.46		1.4	1.1
35	0.38	0.38		1.9	1.3
40	0.28	0.26		1.6	0.62
				1.8	1.3
				1.2	1.4
Digits				0.90	0.97
8	7.4			1.0	0.95
1	9.2		Amber	1.8	0.58
1	7.5		Blue	0.61	0.49

TABLE 9A

Photometric Measurements of Hydraulic Pressure Panel

Legend	Luminance (fL.)	Numerals	Luminance (fL.)
H	0.30	0	0.16
Y	0.29	2 in 20	0.27
D	0.26	0 in 20	0.37
P	0.37	3 in 30	0.39
R	0.24	0 in 30	0.50
E	0.27	4 in 40	0.31
S	0.25	0 in 40	0.29
S	0.24		
P	0.38		
S	0.37		
I	0.35		
X	0.34		
1	0.28		
O	0.29		
O	0.24		

TABLE 9A (Continued)

Photometric Measurements of Hydraulic Pressure Panel

Graduations:	Luminance (fL.) Left	Right	Indicator Scale:	Luminance (fL.) Left	Right
0	0.16	0.16	Red	3.1	2.9
20	0.39	0.38		2.4	1.8
25	0.59	0.42		1.9	1.3
30	0.55	0.51		2.0	2.2
35	0.40	0.30		2.0	1.5
40	0.33	0.28	Green	0.95	1.5
				2.2	2.0
			Amber	4.4	3.8
				3.4	4.0
				5.2	2.7
				5.2	3.9
				3.9	3.4
				4.9	4.1
				2.7	3.3
			Blue	0.56	0.90

TABLE 10A

Photometric Measurements of Control Panel

Legends	Luminance (fL.)	Legends	Luminance (fL.)
A	0.11	O	0.35
M	0.10	N	0.31
P	0.09	O	0.22
S	0.11	F	0.23
L	0.18	F	0.23
R	0.22	L	0.40
A	0.50	T	0.48
U	0.58	/	0.49
X	0.53	T	0.40
P	0.38	E	0.31
W	0.33	S	0.24
R	0.33	T	0.24
D	0.29	D	0.41
I	0.32	I	0.38
G	0.34	M	0.43
I	0.39	S	0.29
T	0.43	E	0.24
		T	0.18

APPENDIX B

SPECTRAL LUMINANCE CURVES

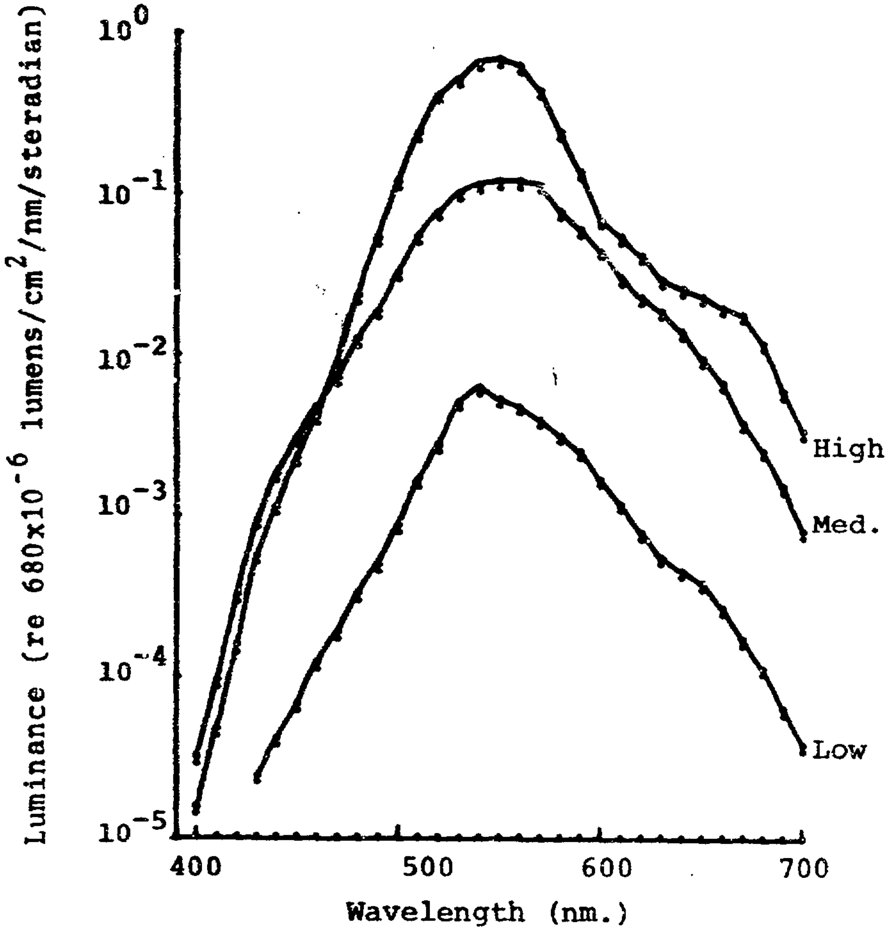

Figure 1B. Photopic luminance—Green indicator lights.

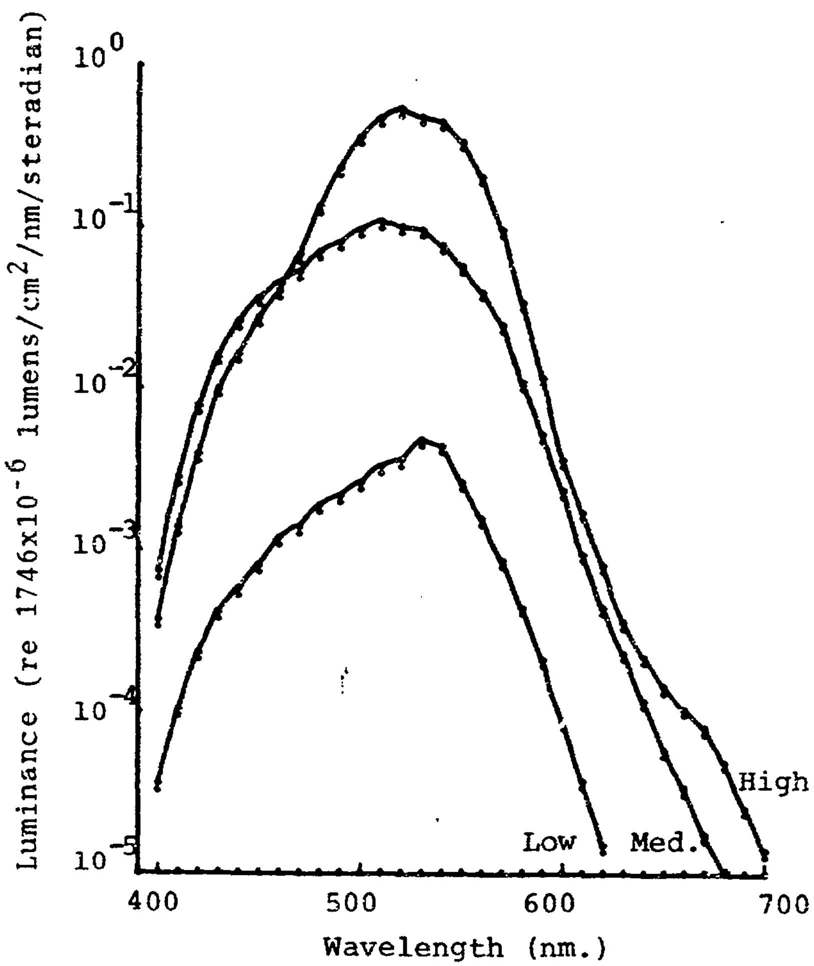

Figure 2B. Scotopic luminance—Green indicator lights.

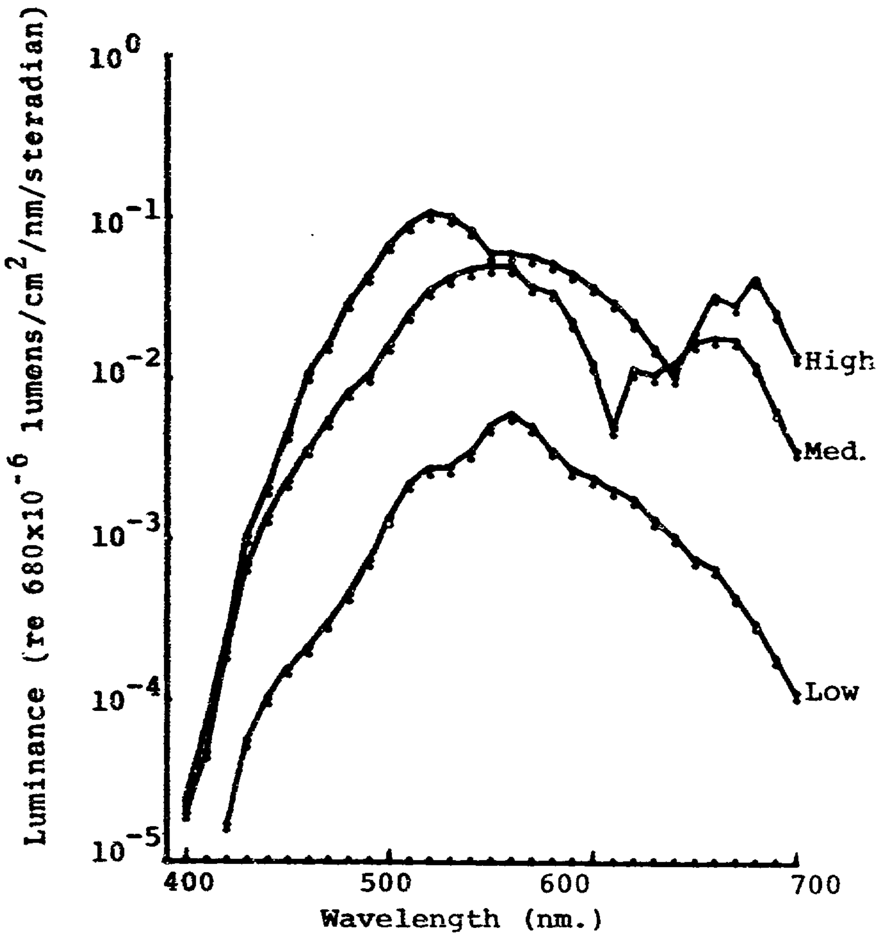

Figure 3B. Photopic luminance—Blue indicator lights.

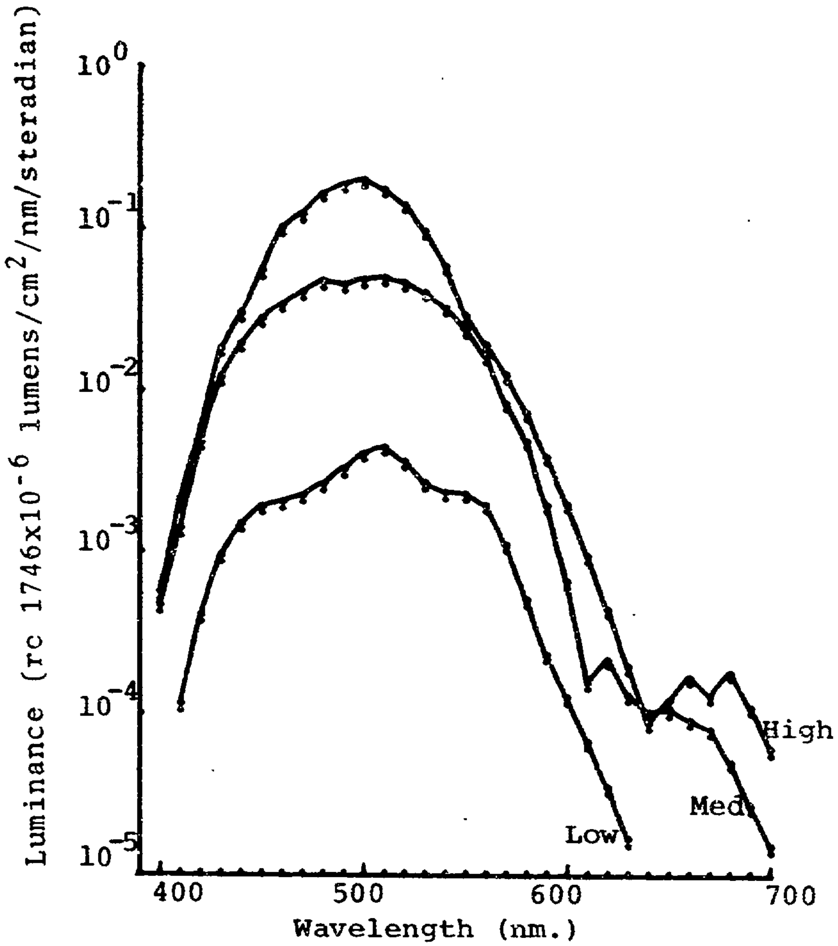

Figure 4B. Scotopic luminance—Blue indicator lights.

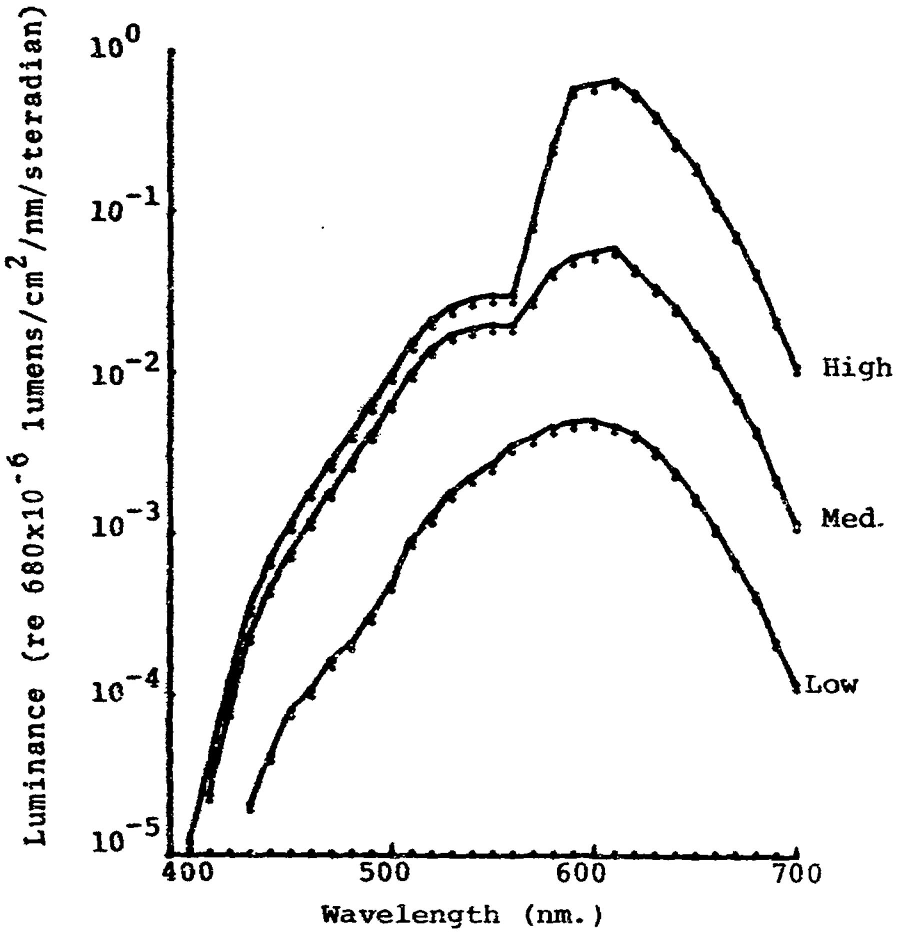

Figure 5B. Photopic luminance—Red indicator lights.

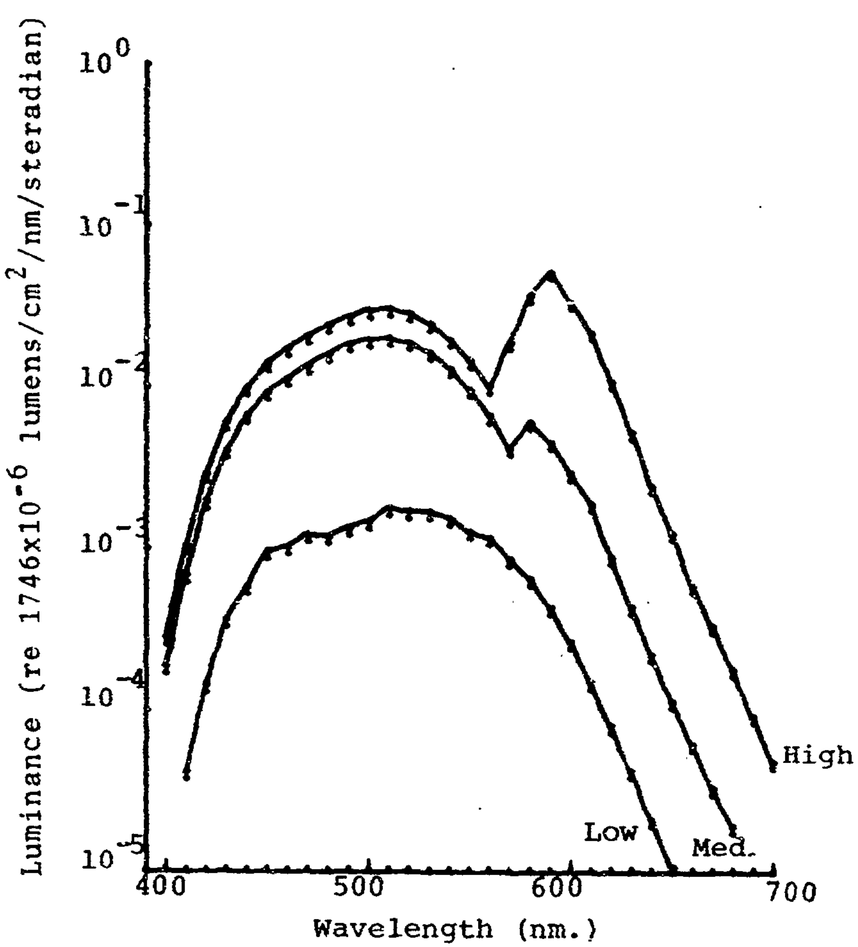

Figure 6B. Scotopic luminance—Red indicator lights.

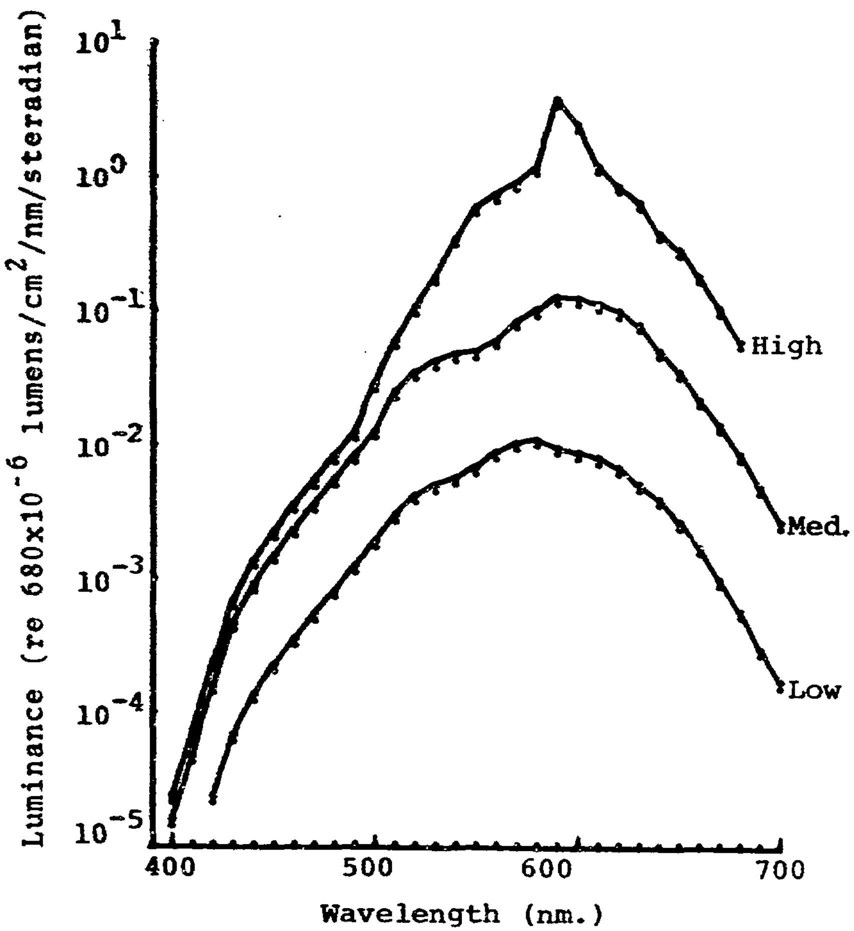

Figure 7B. Photopic luminance—Amber indicator lights.

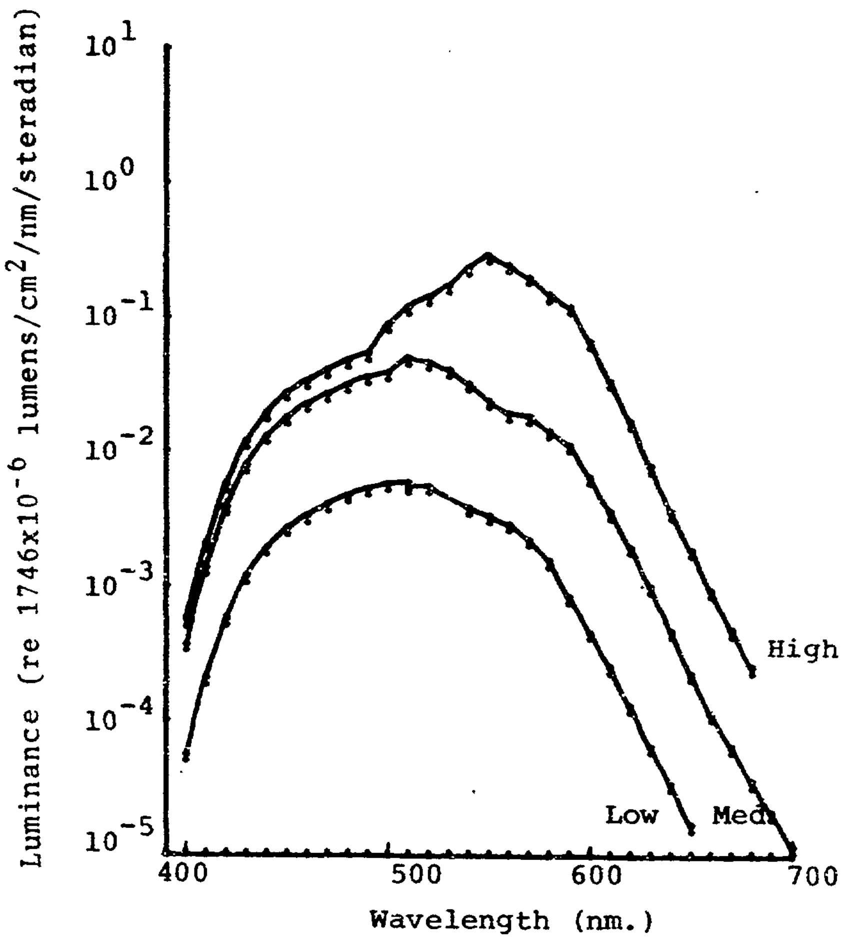

Figure 8B. Scotopic luminance—Amber indicator lights.

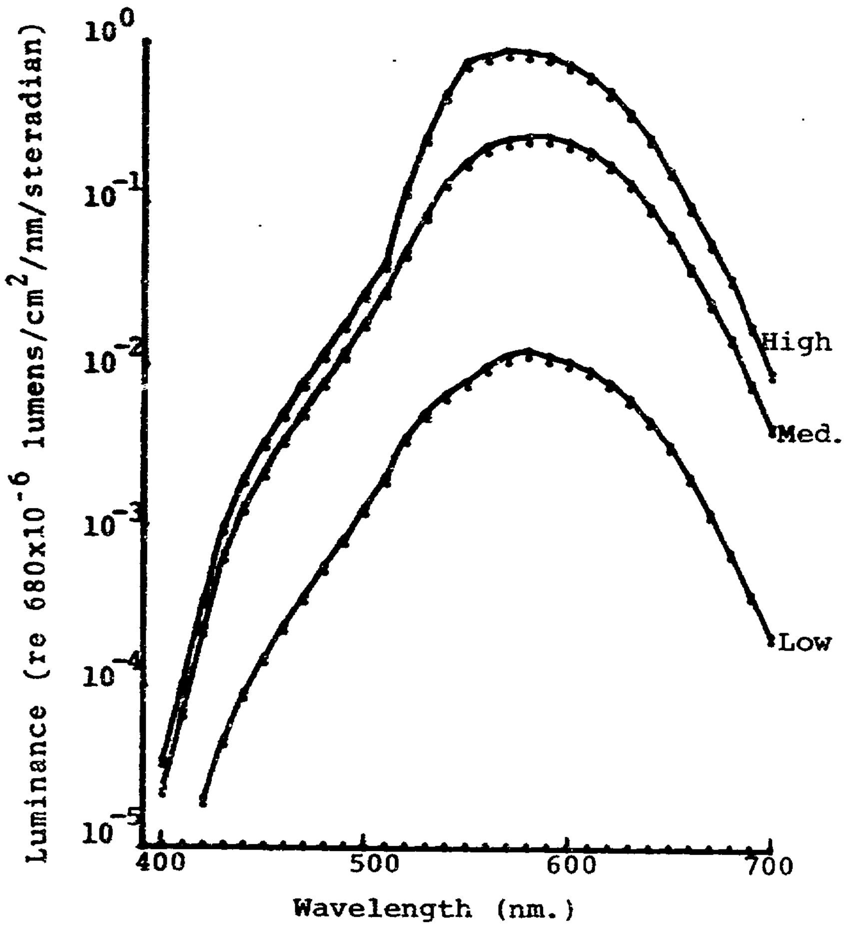

Figure 9B. Photopic luminance—Amber digits.

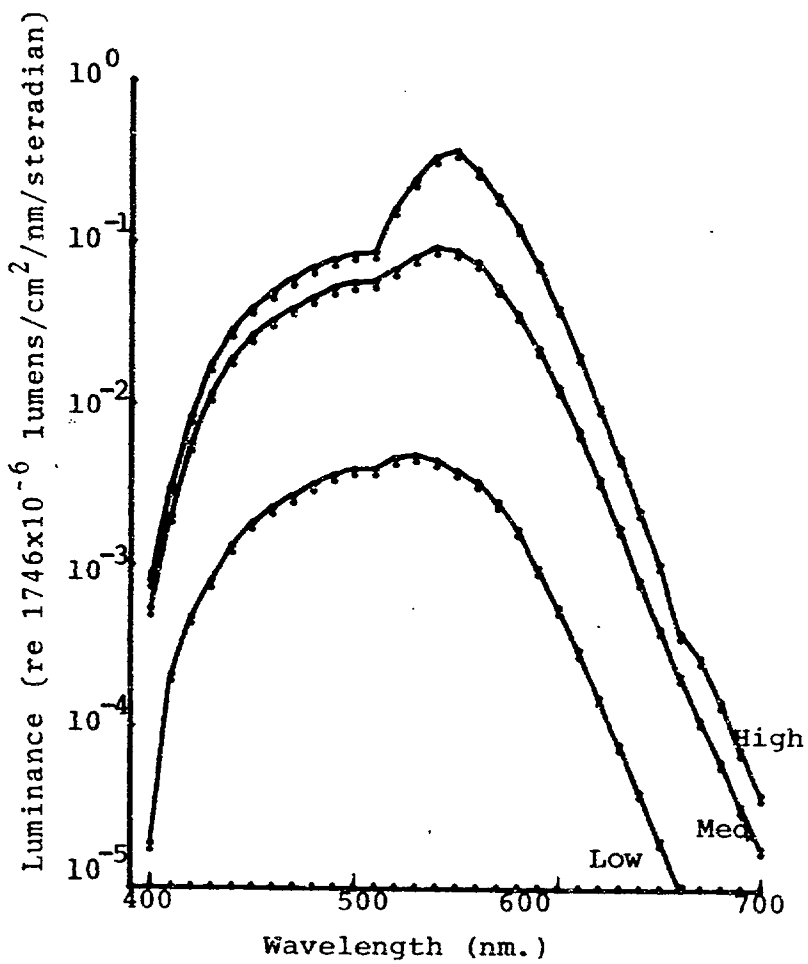

Figure 10B. Scotopic luminance—Amber digits.

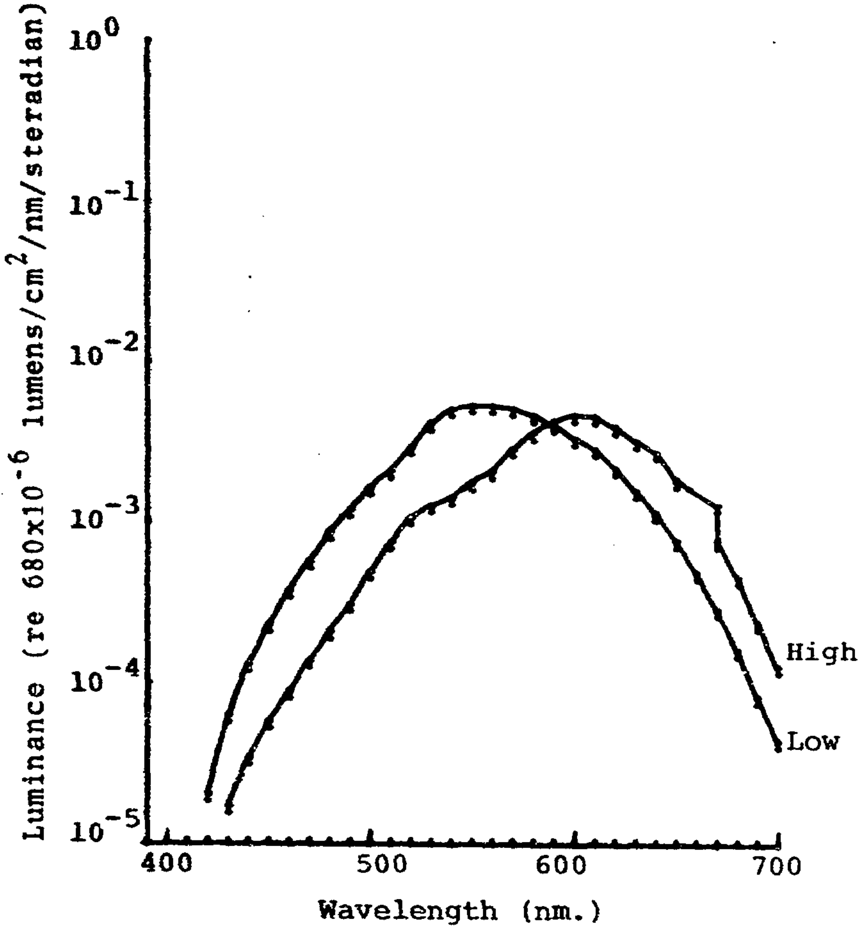

Figure 11B. Photopic luminance—IPL red.

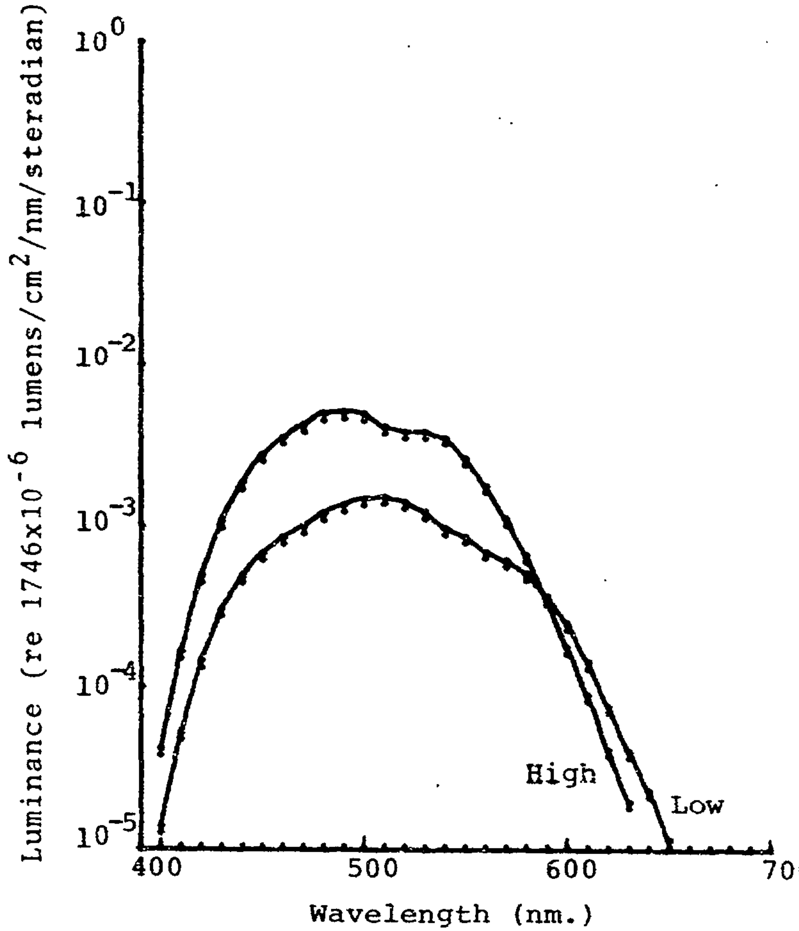

Figure 12B. Scotopic luminance—IPL red.

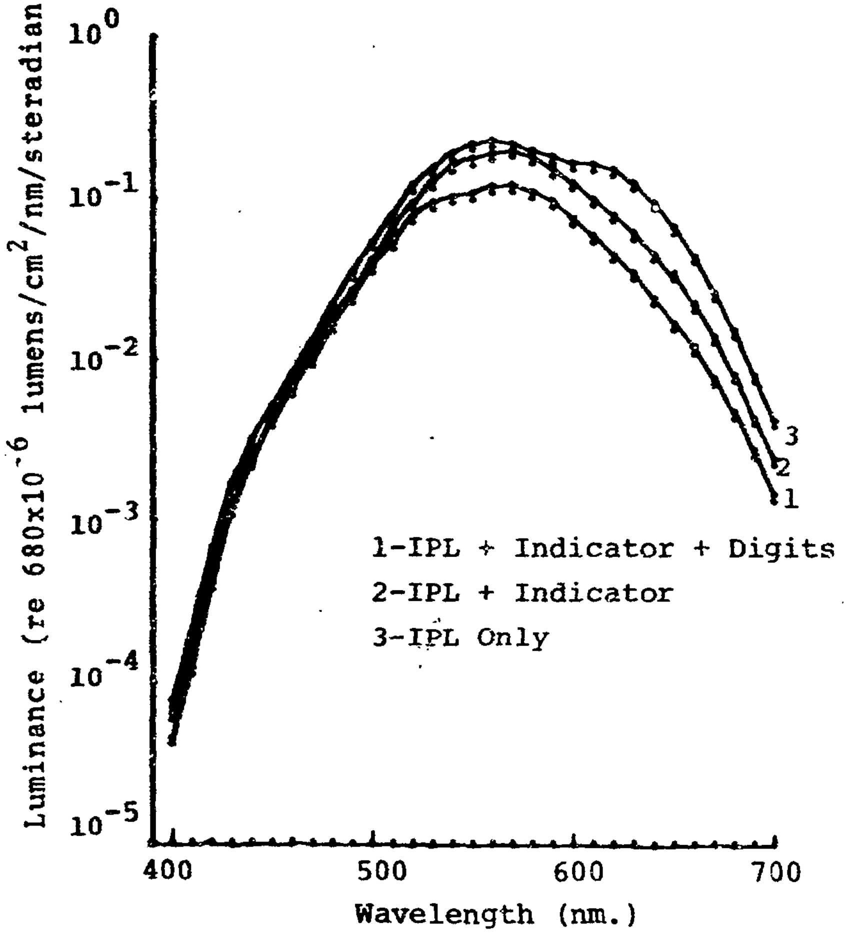

Figure 13B. Photopic luminance—Integrated panel at low level.

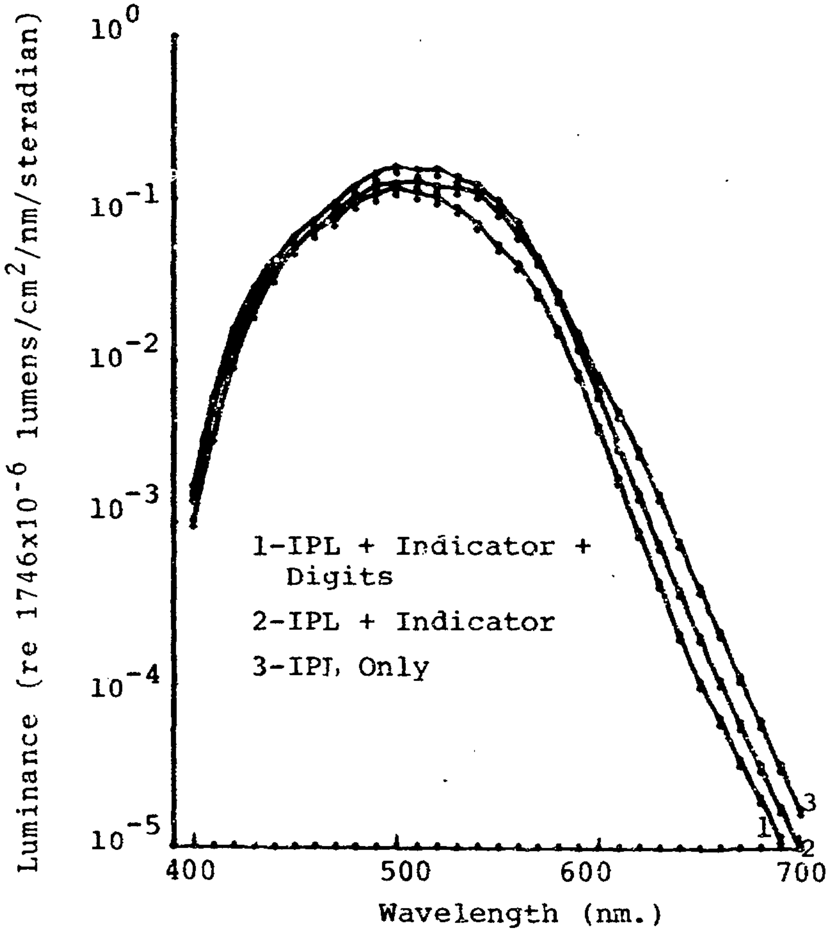

Figure 14B. Scotopic luminance—Integrated panel at low level.

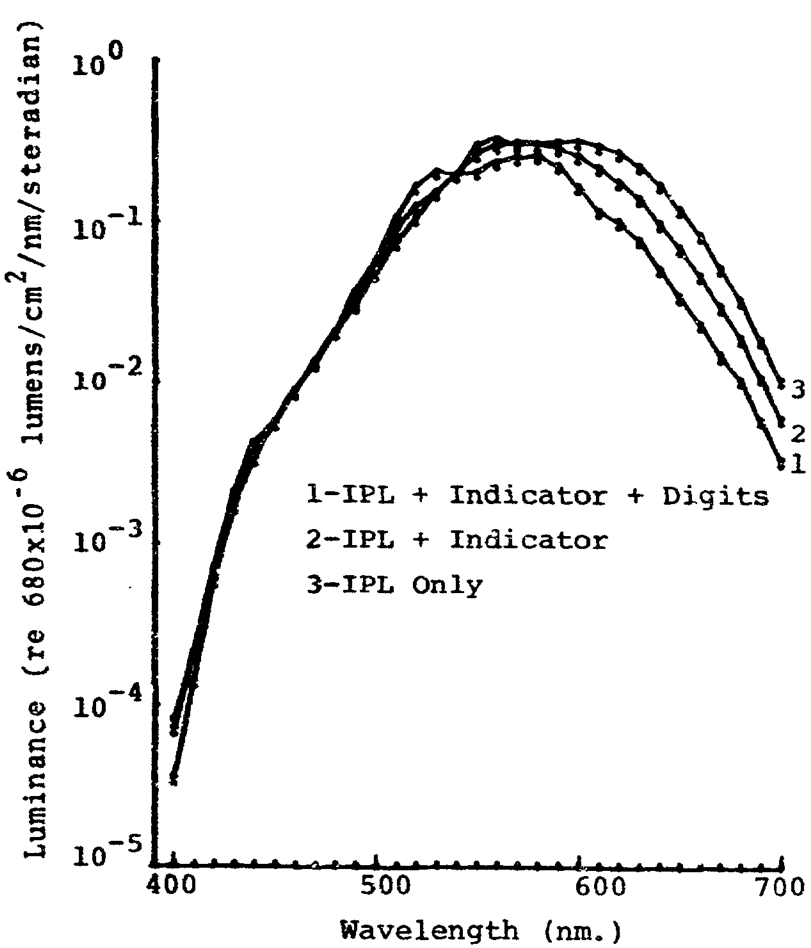

Figure 15B. Photopic luminance—Integrated panel at high level.

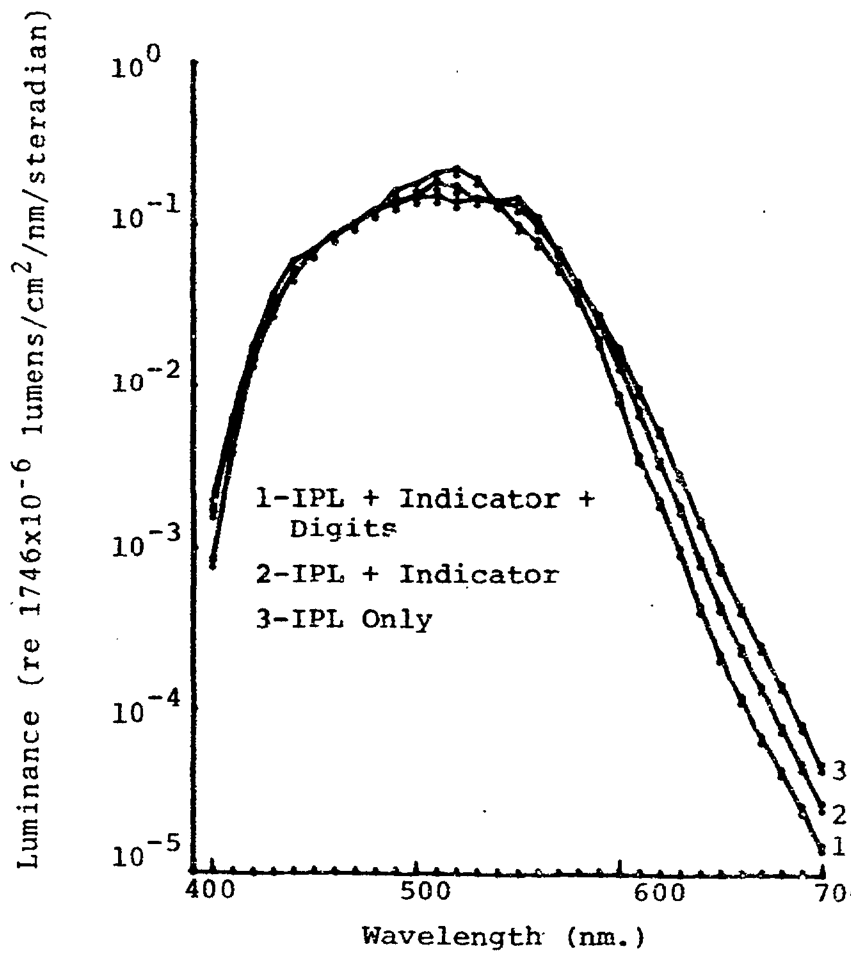

Figure 16B. Scotopic luminance—Integrated panel at high level.

APPENDIX C

RECOMMENDED MARKING SIZES

TABLE 1C

3-Inch Dial Face, or Equivalent Vertical-Scale Instruments

Graduations	Length (Inches)	Stroke Width
Major	0.220	0.030
Intermediate	0.155	0.020
Minor	0.110	0.015
Numeral & Letters, in Order of Criticality	Height (Inches)	Stroke Width
1	0.220	0.024
2	0.155	0.017
3	0.110	0.012

Recommended height-to-stroke-width ratio: 9 to 1.

TABLE 2C

2-Inch Dial Face, or Equivalent Vertical-Scale Instruments

Graduations	Length (Inches)	Stroke Width
Major	0.155	0.020
Intermediate	0.110	0.015
Minor	0.080	0.010
Numerals & Letters, in Order of Criticality	Height (Inches)	Stroke Width
1	0.155	0.017
2	0.110	0.012
3	0.080	0.009

Recommended height-to-stroke-width ratio: 9 to 1.