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LIGHTING SMALL-SHELTER INTERIORS:

CRITERIA AND AN EXAMPLE

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HUMAN ENGINEERING LABORATORIES

ABERDEEN PROVING GROUND, MARYLAND

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ABSTRACT

This report gives lighting criteria and lighting-system design methods for illuminating small-shelter interiors effectively. It summarizes the amounts of light (quantity) currently recommended for representative visual tasks, as well as the practices for controlling light (quality).

Then, to show how these lighting-design methods are actually applied, it describes a lighting system designed for the proposed control cab of a mobile low-power nuclear power plant. This lighting system was evaluated by making a lighting survey in a control-cab mock-up. The results showed the system satisfied the lighting criteria established for the shelter.

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INTRODUCTION

More and more small shelters -- and more kinds of small shelters -- are appearing in military systems, as well as commercial and private applications. These shelters generally house equipment -- electrical and pneumatic test equipment for missile systems, control equipment for small nuclear power plants and missile systems, communication equipment, etc.

Yet these small shelters do not always provide adequate lighting for operators and maintenance personnel to use their equipment effectively. This report examines factors to consider and gives procedures for designing adequate lighting systems for small shelters. As an example, Part II shows how these design methods were used in evaluating lighting for a proposed shelter containing the control equipment for a U. S. Army Mobile Nuclear Power Plant. However, while these methods have general applicability, this report obviously cannot solve all possible lighting problems in every small shelter.

TABLE 1

Levels of Illumination Currently Recommended for Specific Visual Tasks

Work Area or Task	Footcandles on Task[a]
Assembly and Repair	
Rough easy seeing (installing chassis in rack)	30
Rough difficult seeing (component replacement)	50
Medium (soldering wires to a connector)	100
Fine (electronic micromodules)	500
Bench Work	
Rough easy seeing	30
Rough difficult seeing	50
Medium	100
Fine	500
Control Rooms	50
Console Surfaces and/or Panels	50
Dials, Gages, Meters and Scales[b] (on face)	50
Equipment Racks and Panels	30
Emergency Lighting[c]	3
Inspection	
Ordinary	50
Difficult	100
Very difficult	500
Office Work	
Cartography and detailed drafting.	200
Accounting, auditing, tabulating, bookkeeping, business machine operation, reading poor reproductions and rough layout drafting.	150
Regular office work -- reading good reproductions, reading or transcribing handwriting in hard pencil or on poor paper, active filing, etc.	100
Reading or transcribing handwriting in ink or medium pencil on good quality paper and intermittent filing.	70
Reading high-contrast or well-printed material, tasks and areas not involving critical or prolonged seeing, such as conferring and interviewing.	30
Testing	
General	50
Electrical equipment or equivalent	100
Radar Displays (plan position indicator)	0.1[d]
Switch Boards	50
Information Boards	50
Teletype Machines	150

[a] Minimum on task at any time.

[b] A steel scale with 1/64-inch divisions requires 180 footcandles of light for easy reading.

[c] Level measured 30 inches above floor.

[d] Maximum on task at any time for cathode-ray tube using P7 phosphor (3).

LIGHTING CRITERIA

Quantity of Light

Before designing a lighting system, the designer must know how much light (illumination level in footcandles) specific visual tasks require. The more severe the visual task is, the more illumination it requires. For example, a dimly lighted hallway provides enough light to place a key in a keyhole but not enough to thread a needle.

Current illumination levels recommended for specific visual tasks are found in various publications (Ref. 3, pp 35 to 40; Ref. 5, p 103; Ref. 8, pp 9-49 to 9-63). Table 1, based on these recommended illumination levels, shows the minimum illumination levels required for most of the specific visual tasks encountered in small shelters. A small shelter may be defined as one whose three dimensions produce a room ratio of 2.24 or less (explained in greater detail in the section on Lighting-System Design). Regardless of the shelter's size, specific visual tasks determine the illumination levels required. The recommended quantity of light should be provided at the point and in the horizontal, vertical, or intermediate plane where the visual task is performed.

In several applications the visual tasks will vary from those requiring high illumination levels (100 footcandles or more) to those requiring low illumination levels (30 footcandles or less). To satisfy a wide range of illumination levels required for visual tasks in a single application, the lighting system should have a dimming capability (discussed further in the Lighting-System Design section). Various illumination levels are required, for example, in a shelter where radar operators monitor cathode-ray-tube displays and perform maintenance on the equipment. Maintenance will require more light than monitoring the displays. However, if cost or other factors make such a design impossible, the lighting system should provide a constant illumination level that best accommodates the most critical visual tasks -- such as monitoring displays in a radar van -- or the tasks performed most frequently, if no task is especially critical. Sometimes visual tasks are performed at various workplane heights within the shelter. In these complex cases where a single lighting system cannot provide adequate illumination over the total work area, there should be additional lights to supplement the general room lighting. A variety of lighting components can be used for supplementary lighting: spots, dial lamps, fluorescent panels, and trans-illuminated scales, controls and indicators.

TABLE 2

Recommended Surface Reflectances for Interior Surfaces

Surface	Percent Surface Reflectance[a]
Ceilings	80-90
Walls	40-60
Floors	Not less than 20
Work surfaces, desk and bench tops, machines, equipment panels and racks	25-45

[a] Percent of surface reflectance is the ratio of reflected light (foot-Lamberts) to the incident light (footcandles) falling on the surface, i.e., percent reflectance = $\frac{\text{foot-Lamberts}}{\text{footcandles}}$ (100)

Quality of Light

Users must have a certain minimum amount of light to perform visual tasks at all. But given this minimum intensity, the most important factor is quality of illumination. Variables such as glare, contrast or luminance ratio, color, distribution, and diffusion all affect the visual environment compatibility with efficient visual performance.

Glare

Glare is relatively bright light shining into an observer's eyes from a relatively dim visual field he is attempting to observe. His eyes adjust to the brighter light, thus reducing the field's visibility; and the stress of trying to see the field despite the brighter glare makes visual performance uncomfortable and inefficient. Glare may be either direct or reflected.

Direct Glare

An artificial or natural light source within the visual task field produces direct glare. There are several ways to control direct glare:

a. Removing light sources from a cone 60 degrees above and below and to the right and left of the normal line of sight.*

b. Selecting luminaires which meet recommended average luminances and average-to-maximum luminance ratios.

c. Brightening the area around the glare source.

d. Using several less-intense light sources, rather than a few intense ones.

Well-designed lighting fixtures can do much to reduce direct glare.

Direct glare should not be a problem with fluorescent lighting systems giving up to 100 footcandles of average illumination provided that (a) the surface reflectances comply with Table 2, and (b) the luminaires meet recommended criteria (Appendix A, pp 11-2 to 11-5) for crosswise and endwise average luminance distributions as well as average-to-maximum luminance ratios. Incandescent luminaires, which generally have about one-fourth the area of a fluorescent luminaire, may have twice the average luminance values the criteria recommend for fluorescent luminaires.

* Orientation of normal line of sight is from the eye to the visual task area.

TABLE 3

Recommended Maximum Luminance Ratios for Shelter Interiors

Environmental Classification[a]			Condition
A	B	C	
1:3	1:3	1:5	Between tasks and adjacent lighter surroundings.
3:1	3:1	5:1	Between tasks and adjacent darker surroundings.
10:1	20:1	NP[b]	Between tasks and more remote darker surfaces.
1:10	1:20	NP	Between tasks and more remote lighter surfaces.
20:1	NP	NP	Between luminaires and surfaces adjacent to them.
40:1	NP	NP	Between the immediate work area and the remainder of the environment.

[a] A -- Interior areas where reflectances of entire space can be controlled.
B -- Areas where reflectances of immediate work area can be controlled but control of remote surroundings is limited.
C -- Areas where it is completely impractical to control reflectances and difficult to alter environmental conditions.

[b] Luminance ratio control not practical.

Somtimes it is impossible to avoid sources of direct glare within the 60-degree cone. Such sources can be tolerated, however, if they are not more than five times as bright as the surrounding area (Table 3 and Luminance Ratio section). If supplementary lighting sources produce direct glare, a low-luminance diffuser, hood or visor can prevent direct rays of light from entering the eye.

Reflected Glare

Reflected glare is a reflection of a light source within the visual field. For example, a console operator may see the image of a light source reflected from the protective glass of a meter. Reflected glare is controlled by:

a. Diffusing reflected light with matte (non-glossy) finishes on the visual task area and its surroundings.

b. Using materials and colors which increase the luminance of the field surrounding the glare source.

c. Locating work surfaces with respect to the light sources so that unwanted light is reflected away from the observer's eyes (existing surfaces may be checked by moving a mirror along the surfaces).

d. Changing the character of a surface to eliminate a specular (mirror-like) reflection and the resulting reflected glare.

e. Using low-luminance luminaires.

If it is not possible to observe these recommendations, the reflected luminance of the light-source image should not exceed 350 foot-Lamberts.

Luminance Ratio

Luminance ratio is the luminance of surroundings relative to the visual task area or other specified surfaces. To allow the eyes to function comfortably and efficiently, luminance ratios should be kept within the limits given in Table 3 (Ref. 5, p 103). These recommended limits will be met if the surface reflectances comply with Table 2 and recommendations for controlling glare have been observed. If ambient illumination must be dimmed, any legend lights and illuminated displays on the equipment should also be dimmable to keep luminance differences between the lights, displays, and adjacent surfaces within the recommended luminance ratios in Table 3.

TABLE 4

Recommended Paint Colors for Interior Surfaces

Surface	Federal Standard No. 595 Color Number[a]	Color
Ceiling	27875[b]	White
Walls	24410, 24533, 34410	Green
Floor	36118, 26231, 36231	Gray
Equipment Racks, Cabinets, and Console Exteriors	24410	Green
Equipment Panels and Console Panels	26492, 26373, 36492, 26307	Gray
Handles and Lettering	37038	Black

[a] Color numbers 24533, 34410, 26231, 36231, 26373, 36492, and 26307 do not comply with AR 746-5; however, they are satisfactory for commercial equipment.

[b] Recommended for applications where visual tasks require 50 footcandles or more of ambient illumination; otherwise, 24410 may be used.

Color

The colors used on interior surfaces will establish surface reflectances and luminance ratios; therefore, it is important to use those colors which provide surface reflectances and luminance ratios within the limits stated in Tables 2 and 3. Colors which satisfy the criteria of Tables 2 and 3 are listed in Table 4.

Paragraph 46e of AR 746-5 (2) states that commercial items originally procured in non-standard colors will be maintained in those colors. But when they must be painted, standard colors will be used. The colors given above are examples; many other available colors also satisfy the criteria in Table 2.

Distribution and Diffusion

Proper light distribution and diffusion will aid in minimizing shadows in the visual environment. Distribution of light (uniformity) is considered satisfactory if the maximum and minimum values of illumination in the room are within 17 percent of the average illumination level* (Ref. 8, p 9-16). For example, the horizontal footcandles measured at a point in front of an equipment rack may be 42 footcandles, and the horizontal footcandles measured on a console desk may be 58 footcandles. If the average illumination is 50 footcandles, the uniformity is satisfactory. To get satisfactory distribution, luminaires must be mounted within their recommended spacing-to-mounting height ratios -- generally, it is desirable to space them closer together than these limits -- and supplementary luminaires should be provided for visual task areas which are shaded from the ambient lighting system. Shadows are reduced if the light is diffused and comes from several directions. Properly distributed and diffused light will help to reduce luminance ratios.

* Measurements must be taken on the same workplane.

TABLE 5

Comparison of Fluorescent and Incandescent Lighting Sources

in Identical Installations Providing Equal Footcandles

Design Factors	Fluorescent	Incandescent
Initial cost (installation)	Higher	Lower
Operating cost	Lower	Higher
Efficacy	More lumens per watt 30-80 lumens/watt	Less lumens per watt 10-23 lumens/watt
Distribution and diffusion of light per luminaire	Better	Poorer
Power required	Less	More
Lamp life	Longer (7-18 times life of incandescent)	Shorter (approximately 1000 hours per lamp)
Generates radio-frequency interference	Yes	No (essentially nonexistent)
Radiant heat generated	Less	More
Environmental stress	Lower reliability in extreme temperature and/or vibration. Less light output outside optimum temperature range (40-110° F.)	Withstands more environmental stress (temperature extremes, vibration, shock)
Recommended use	General lighting where space is relatively ample and environment is controlled.	General lighting where extremes of environment are encountered and where space is limited.

LIGHTING-SYSTEM DESIGN

The first steps in designing a lighting system are identifying the visual tasks that must be done and determining the amount of light these tasks require. Table 1 shows the minimum values required for tasks done in most shelter interiors. If illumination requirements vary greatly, it is usually most practical to select an average illumination level that will be reasonably uniform throughout the shelter; this average illumination level should usually be chosen by compromising what is required for the tasks that require the most light and the tasks that are performed most frequently. The lighting-system design is then detailed from the procedures below.

Selecting Lighting Sources

The preferred light sources for interior lighting are incandescent and fluorescent. The choice depends largely on economic and environmental factors (Table 5).

Performing Lighting Calculations

Interior Illumination Level

The Lumen Method of calculation is used most frequently to find how many lamps or luminaires are required for a given illumination level (i.e., the average of all points on an interior workplane). The Lumen Method is based on the footcandle, defined as one lumen per square foot; that is,

$$\text{Footcandles} = \frac{\text{lumens}}{\text{area in square feet}} \qquad (1)$$

But not all of the lumens the lamp(s) generate can reach the workplane, because of losses in the luminaire and at the interior surfaces, so the lamp lumens must be multiplied by a coefficient of utilization (CU); that is,

$$\text{Coefficient of Utilization} = \frac{\text{lumens reaching specified work surface, both directly from luminaire and by interreflection}}{\text{lumens generated by the lamps}} \qquad (2)$$

Equation (1) then becomes:

$$\text{Footcandles} = \frac{\text{lamp lumens} \times \text{CU}}{\text{area in square feet}} \qquad (3)$$

While equation (3) gives the initial illumination level for a new installation, the design objective is determining how many lamps are required to maintain the average illumination level. Thus other factors must also be considered, to account for progressively degraded lamp output and light losses from dirt that collects on the luminaire surfaces. Equation (3) becomes:

$$\text{Maintained Footcandles} = \frac{\text{lamp lumens x CU x LLD x LDD}}{\text{area in square feet}} \qquad (4)$$

where:

CU = Coefficient of utilization

LLD = Lamp lumen depreciation factor

LDD = Luminaire dirt depreciation factor

Because a luminaire consists of lamps, supporting structure and diffuser, equation (4) may be written in more useful forms:

$$\text{Lamp Lumens} = \frac{\text{maintained footcandles x area in square feet}}{\text{CU x LLD x LDD}} \qquad (5)$$

or

$$\text{Luminaires} = \frac{\text{maintained footcandles x area in square feet}}{\text{lamps per luminaire x lumens per lamp x CU x LLD x LDD}} \qquad (6)$$

Calculating the Coefficient of Utilization

The actual CU will depend on the specific luminaire that is selected;* however, the CU can be estimated from data in Appendix A, Figures 9-3 to 9-5. The first step is calculating cavity ratios for the ceiling cavity, room cavity, and floor cavity by using this formula:

$$\text{Cavity Ratio} = \frac{5h\,(\text{room length} + \text{room width})}{\text{room length x room width}} \qquad (7)$$

* For each commercially available luminaire, specific photometric data are supplied for obtaining the CU.

where:

$h = h_{RC}$ for the room cavity ratio

$= h_{CC}$ for the ceiling cavity ratio

$= h_{FC}$ for the floor cavity ratio

The values for h_{RC}, h_{CC}, and h_{FC} are the vertical heights from luminaire plane to workplane, luminaire plane to ceiling, and workplane to floor, respectively. The floor and ceiling cavity ratios are also equal to:

$$FCR = RCR \frac{h_{FC}}{h_{RC}} \qquad \text{and} \qquad CCR = RCR \frac{h_{CC}}{h_{RC}}$$

The second step is determining the effective Ceiling (ρ_{CC}) and Floor (ρ_{FC}) cavity reflectances (Appendix A, Fig. 9-3). Except when estimating initial illumination, use expected maintained ceiling, floor, and wall reflectances to determine the effective cavity reflectances. Since most small shelters have ceiling-mounted luminaires, the Ceiling Cavity Ratio is zero, and the ceiling reflectance may be used as the effective Ceiling Cavity reflectance.

The last step uses the values from steps 1 and 2 with Appendix A, Figure 9-4, to get the approximate CU. Interpolation is usually necessary to find the CU for the exact Room Cavity Ratio. Figure 9-4 in Appendix A gives coefficients of utilization for various representative types of luminaires; therefore, it is essential to use the coefficient for the luminaire most like the one that will actually be used in the shelter. After a specific luminaire has been selected, the photometric data accompanying it will give the actual CU, which is then substituted into equation (5) to find how many lamp lumens are required. Because the Zonal Cavity Method for calculating the CU is relatively new, photometric data for luminaires may provide the CU in terms of Room Index, which has been in use for some time, rather than in terms of RCR. Room Index is calculated from Table 6 and the equation:

$$\text{Room Ratio} = \frac{\text{width x length}}{\text{mounting height of luminaire above workplane} \times (\text{width} + \text{length})} \qquad (8)$$

The coefficients of utilization assume empty interiors; therefore if the shelter's interior configuration makes it smaller or irregular, these reductions in room volume and workplane must be considered in calculating cavity ratios. For purposes of calculating cavity ratios, items such as equipment racks, work benches, and storage cabinets do not effectively reduce the room dimensions.

TABLE 6

Room Ratio Ranges and Room Index[a]

Room Index	Room Ratio Range
A	More than 4.50
B	3.50 to 4.50
C	2.75 to 3.49
D	2.25 to 2.74
E	1.75 to 2.24
F	1.38 to 1.74
G	1.12 to 1.37
H	0.90 to 1.11
I	0.70 to 0.89
J	Less than 0.70

[a] Adapted from Westinghouse Lamp Division (11).

For irregular rooms, the RCR can be calculated as follows:

$$RCR = \frac{2.5 \times \text{wall area of room cavity}}{\text{workplane area}} \quad (9)$$

Determining LLD and LDD Factors

Lamp lumen depreciation is caused by aging. The amount of depreciation can be determined from manufacturers' performance data. The LLD factor compares the lamp's output when new and when due for replacement according to a lamp-replacement schedule. Figure 9-6 in Appendix A gives an average of manufacturers' data for several frequently used lamps at 70 percent of rated average life. For example, the LLD for a fluorescent rapid-start 430-milliampere cool white lamp is 0.87 for six hours per start.

Luminaire dirt depreciation arises from dirt that collects on the luminaire and its components. Luminaires are classified into six different categories by their characteristics of attracting and retaining dirt. Use Figures 9-7 and 9-8 in Appendix A to calculate the LDD factor. For example, a luminaire in category 5 operating in a clean environment and cleaned once a year has an LDD of 0.88.

After determining the CU, LLD, and LDD factors, solve equation (5) to determine the lamp lumens required to maintain the average illumination level.

There are point-by-point methods for calculating illumination levels at specific points; unfortunately, they are not usually valid for calculating illumination levels in small shelters, because the distance from the point to the lighting source is usually less than five times the luminaire's maximum dimension. But if these methods are applicable, see the procedures in the 4th edition of the IES Lighting Handbook (pages 9-21 to 9-26).

Interior Luminance (Brightness) Levels

The luminances of surfaces in the visual environment must be determined to ensure good visual performance and comfort. The average luminance levels of ceiling and walls are calculated as follows:

a. Calculate the Room Cavity Ratio.

b. Determine percent wall reflectance and effective ceiling cavity reflectance.

c. From Figure 9-34 in Appendix A find the wall and ceiling cavity luminance coefficients for the type of luminaire distribution that will be used.

d. Use the following relationships to calculate the luminance of the wall and ceiling cavities:

$$\text{Average Initial Wall Luminance} = \frac{\text{total lamp lumens} \times \text{wall luminance coefficient}}{\text{floor area}} \quad (10)$$

$$\text{Average Initial Ceiling Cavity Luminance} = \frac{\text{total lamp lumens} \times \text{ceiling luminance coefficient}}{\text{floor area}} \quad (11)$$

The Lumen Method assumes that:

a. Luminaires are located so they will distribute light reasonably uniformly.

b. Coefficients of utilization are based on empty interiors. Interiors with extensive vertical obstructions may simulate a smaller room and, thus, require a different CU.

c. Luminaires are installed so they provide their rated output. Variables such as line voltage, unseasoned lamps, and temperature may cause discrepancies between measured and computed illumination levels.

Selecting Lighting Components

A review of lighting-component catalogues reveals that lighting components are available in standard sizes only. Fluorescent lamps come in standard lengths, diameters, wattage, lumens, etc.; fixtures are available only in certain styles and sizes.

Designers must be familiar with the many kinds of lighting components commercially available, so they can quickly and easily find components that will be compatible with their particular shelters.

Determining Compatibility between Lighting System and Shelter

After briefly reviewing available lighting components, and especially luminaire sizes, the designer selects the luminaires which will fit into the available ceiling space. The number of luminaires can be calculated from Equation (6). In some cases, it may be necessary to relocate air-conditioning ducts, cable ducts, escape hatches, etc., to provide enough mounting space. If there will be two or more rows of luminaires, the required mounting space will depend on the manufacturer's recommended ratio of spacing to mounting height (from the floor). For example, a luminaire with a factor of 1.35, mounted 76 inches above the floor, requires spacing luminaires no farther apart than (1.35) (76) = 102 inches.* For many small shelters, one row of fluorescent luminaires will suffice; however, a lighting system using incandescent luminaires might require more than one row. To make illumination more uniform, it is generally desirable to space luminaires closer than their maximum allowable separation.

When luminaires are mounted in the ceiling, it may be impossible to recess them completely, and the protruding parts may be a hazard. False ceilings can protect personnel from sharp corners of protruding luminaires but they do not provide any additional head clearance. The minimum depth for commercially available fluorescent luminaires is approximately three inches; so if the maximum ceiling-recess depth is less than three inches, and head clearance is a problem, the overall ceiling-to-floor height must be increased. There are fluorescent strip units that mount in depths less than three inches, but these exposed lamps may be damaged accidentally and personnel could be injured. Strip units should be used only in locations where there is little danger of damage and injury.

* If the luminaire is recessed in the ceiling, as most shelter lighting systems are, use the ceiling-to-floor height.

Dimming Provisions

If the visual tasks in any application require widely differing illumination levels, the lighting system should have a dimming control. For example, monitoring a radar display requires low ambient illumination (no more than 0.1 footcandle), but maintaining the same display may require 50 footcandles or more. Dimming controls also make it possible to compensate for aging and dirt: new lamps, which are clean and bright, require the most dimming, and dimming is gradually reduced as dirt accumulates and lamp output begins to fall off.

Components are readily available for dimming both fluorescent and incandescent lighting systems. An incandescent lighting system is normally dimmed by a variable auto-transformer controlling the voltage applied to the lamp filaments. A fluorescent lighting system can be dimmed either by a variable transformer and separate lamp ballasts or by a silicon controlled rectifier (SCR) unit and special ballasts (Ref. 6, pp 249 to 254). For both methods of dimming fluorescent systems, type 40WT12RS lamps must be used.

Although the SCR unit is more expensive than a variable transformer to control the same lighting load, the SCR unit's compactness may be an important advantage when space is at a premium.

If dimming is required, at least 50 inches of space must be allowed for the length of each fluorescent luminaire. This limitation must be considered in making lighting calculations and arranging equipment in the shelter.

SCR dimmers must have at least a minimum lamp load for reliable dimming. Some units require at least six lamps. Others require a minimum of only two or four lamps, which is more nearly the number used in a small-shelter lighting system. SCR dimmers are also available for dimming incandescent lighting systems.

ADDITIONAL FACTORS

Several other factors must be considered in designing a lighting system.

Dark Adaption

In some military night operations, personnel working in a shelter may have to leave it suddenly and go to a dark, possibly hostile, environment. When eyes adapted to normal illumination in the shelter are moved into a very much lower level of illumination, they take time to adjust their sensitivity to the new environment -- personnel will not be able to see objects clearly for approximately 15 minutes or more. The time it takes to adapt to darkness depends heavily on the initial level and color of illumination, and particularly on the individual himself.

Dark adaption is faster if personnel perform their normal tasks in red (wave lengths of 620 millimicrons and above) ambient light. But using a red lighting system means visual tasks must be designed so personnel can perform them with low levels of illumination. It is not feasible to make the red light as bright as ordinary white light would be; that much red light would require much more power and possibly even a separate unit to cool the lighting system. Where a red lighting system is necessary to provide for dark adaption, it should provide enough illumination on the panel and indicator markings so the brightness of the markings is at least 0.02 foot-Lambert but not more than 0.1 foot-Lambert (Ref. 10, p 79).

Display and Legend-Light Masking

Display and legend lights are a common problem worth additional emphasis here. Equipment designers should select display and legend lights or switch indicator components that will be clearly perceived as on or off under the required level(s) of ambient illumination.

Maintenance

Any lighting system should be designed for ease of maintenance. It is always desirable, though not always possible, to use luminaires in which bulbs can be replaced without tools. Other lighting-system components, such as fuses, ballasts, etc., should be easily accessible and easy to replace. Lighting components located behind access covers in the luminaires should be clearly indicated by labels placed where they are easily seen.

For additional information on maintenance, see reference 8, pp 10-14 to 10-22.

Emergency Lighting

Emergency lighting systems should be provided wherever a failure of the normal lighting system would degrade system operation or create a potential hazard to personnel. The kind of emergency system required will depend on how greatly a lighting failure degrades the system's operation. It takes much less illumination for personnel to leave a shelter (as a normal procedure in case of a power failure), for example, than for monitoring a display such as a meter. The emergency lighting system should switch on automatically when the normal lighting system fails.

Flicker from Fluorescent Lamps

Flicker is an undesirable characteristic of fluorescent lamps. Because the fusion frequency varies from person to person, some individuals may notice flicker more than others, although few eyes can detect flicker above 60 cycles a second. However, because the periphery of the retina is more sensitive to flicker, people are more likely to notice fluorescent-lamp flicker out of the corner of their eyes than in the direct line of sight. Wherever it is noticed, this flicker may irritate or distract people who must perform difficult visual tasks.

Flicker in fluorescent lamps arises from the characteristics of the phosphor being excited by the cyclic arc current. Largely independent of lamp size and wattage, the degree of flicker depends on the type of phosphor, power supply frequency, and ballast circuit. The designer can reduce flicker by connecting half of the lamps to a lead power-factor circuit and the other half to a lag power-factor circuit, or by using a three-phase power source. In effect, either of these methods raises the flicker frequency above the average eye's 60-cycle fusion cutoff. If neither method

is feasible, designers should select fluorescent lamps with a low flicker index. (This index ranges from zero, for steady light, to one, for a high degree of flicker.) (Ref. 8, Fig. 8-31)

Radio-Frequency Interference from Fluorescent Lamps

Radio-frequency interference (RFI) is generated by the mercury arc in fluorescent lamps. This interference may degrade the performance of equipment such as computers and communication sets. RFI can be greatly reduced by power-line filters, shielded conductors and specially designed lens (diffuser) units which pass light but block RFI energy.

Separation Between Fluorescent Lamp and Housing

Some lighting systems use different sizes or makes of luminaires. Even if two different luminaires have the same number and type of lamps, their luminances may vary; if the luminances vary significantly, they will not distribute light evenly over the workplane. When circumstances require using differing luminaires, they should always be tested to assure that any luminance differences do not violate the criteria in Table 3. Too-large differences can sometimes be reduced by modifying the larger luminaire internally so its inside dimension is equivalent to the other luminaire -- for example, the internal wiring cover might be lengthened or widened.

Frequency

Incandescent and fluorescent lamps can be operated on several different frequencies of alternating current (AC). The most common frequencies are 60, 360, 400, and 840 cycles. Incandescent lighting circuits can be used at any of these frequencies without modification, but fluorescent lighting circuits must be tailored to a particular frequency. As the power-source frequency increases, the reactance must be changed, and the supply voltage must be increased. Operating fluorescent lamps on higher frequencies reduces lighting costs because higher frequencies are more efficacious.

Blackout Lighting

Some military applications require a blackout lighting system so personnel can enter or leave the shelter without letting any light escape. The simplest way to meet blackout requirements is to automatically switch off all lights in the shelter whenever an exterior door is opened. Yet sometimes meters, dials and other areas must be illuminated even during the brief time someone is entering or leaving the shelter. When normal illumination must be maintained, there should be blackout curtains, sub-doors and inter-locks for turning off all lights between the curtains and exterior doors. Therefore, when arranging equipment in shelters used under blackout conditions, designers should locate equipment that requires continuous monitoring away from exterior doors or hatches.

PART II: LIGHTING DESIGN APPLICATION

INTRODUCTION

A lighting system design proposed by Aerojet-General Nucleonics (AGN) for the control cab of the ML-1A Mobile Nuclear Power Plant demonstrates the application of most of the principles and factors of lighting presented in Part I. This lighting-system design was verified by a survey performed in a plywood mock-up of the ML-1A control cab (Figs. 1 and 2).

LIGHTING SYSTEM DESIGN

ML-1A Control Cab

The following paragraphs are quoted from the AGN design report on the ML-1A (Ref. 1, pp 2-8 to 2-9):

> The control cab [Figs. 3 through 6] contains the instrumentation and controls for operation of the power plant, and satisfies the following criteria: one man operation; controls within easy reach; logical grouping of controls; easy accessibility to all rack-mounted instruments; controlled environment; 2 1/2-ton maximum weight; dimensions [138 inches long, 87 inches wide, 77 1/2 inches high] compatible with the bed of an M-35 truck; and acceptable radiation dose rate for the operator.
>
> The instruments, controls, and power circuits in the control cab which allow the operator to control the reactor and power-generating equipment include: the nuclear instrumentation and control components; the control rod position indicators, safety circuits, and interlocks; process instrumentation and control components (temperature, pressure, liquid level in the fluid systems); and all indicators and controls for electrical power distribution.

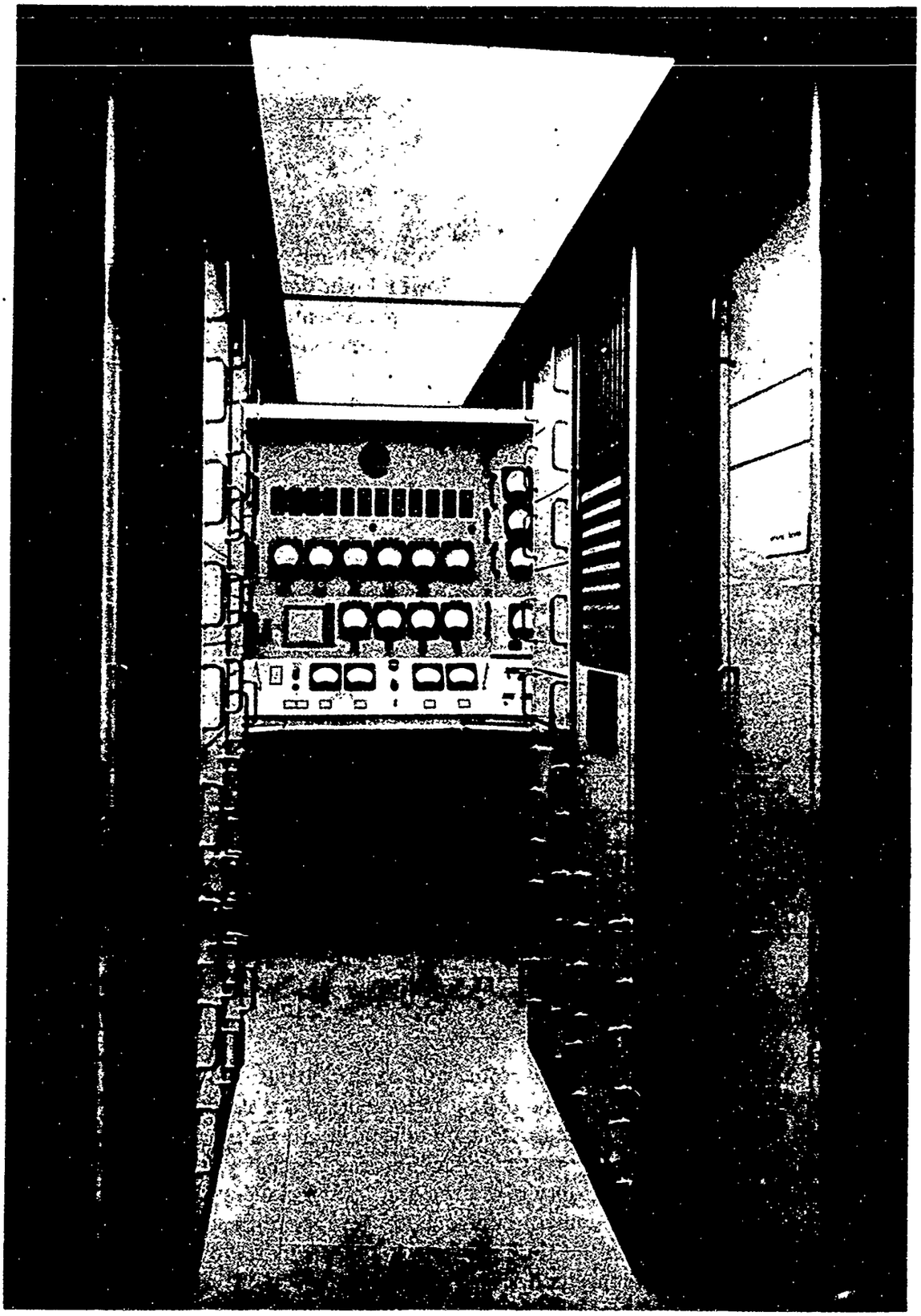


Fig. 1. INTERIOR OF ML-1A CONTROL CAB MOCK-UP,
SHOWING LUMINAIRES, EQUIPMENT RACKS AND OPERATOR'S CONSOLE

The cab structure [U. S. Army Signal Corps Type S-141] meets Signal Corps and Air Force requirements for land and air transport. Air conditioning, heating, and lighting are installed in the shelter to provide a suitable working environment for the power plant operator.

The control console [Fig. 5] is designed to functionally group all instruments and controls within easy reach of the operator. The console is designed as a unit and provides three major information and control categories: process instrumentation and controls; nuclear instrumentation and control; and electrical power instrumentation and control. The console panel assemblies provide accessibility from the front to minimize the requirement to perform maintenance work behind the console. All panels are captive-mounted to the console by hinges at one edge to facilitate maintenance. The console base is utilized for storage of spare parts and mounting of components requiring only infrequent maintenance.

Figure 3 shows the control cab's floor-plan arrangement of the five equipment racks, operator's console, and storage closet. An escape hatch is located in the ceiling above the fold-down seat. The equipment racks, operator's console, and storage closet extend from the floor to the ceiling (Figs. 4 and 6). There are slide-out desks on each side of the console operator.

Visual Tasks and Illumination Levels Required

The visual tasks operators are expected to perform and the recommended illumination levels for them are given in Table 7.

To meet the recommended levels for these tasks, the ML-1A control-cab lighting system must provide from 30 to 100 footcandles of illumination. AGN selected a fluorescent lighting system to provide 100 footcandles of illumination and distribute the light uniformly, yet minimize power requirements. A dimming control was also provided.

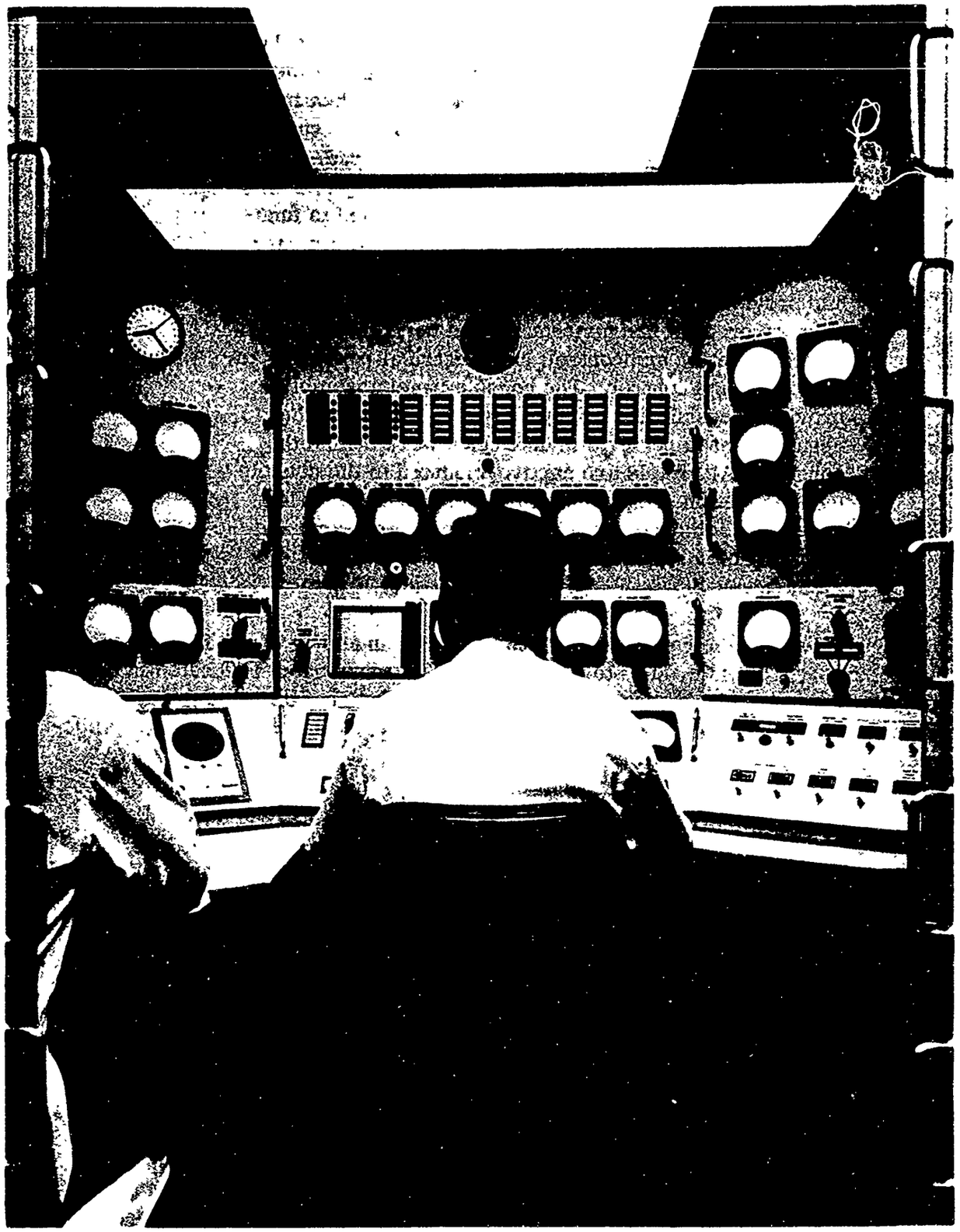


Fig. 2. INTERIOR OF ML-1A CONTROL CAB MOCK-UP
SHOWING LUMINAIRES AND OPERATOR'S CONSOLE

Lighting Calculations for ML-1A Control Cab

The practical workplane area in the ML-1A control cab is about 40 square feet (Fig. 3); however, assuming an empty interior, the workplane area is 70.6 square feet. The workplane's height above the floor is the height of the console desk above the floor, or 30 inches. The approximate surface reflectances are:

Ceiling	80%
Equipment, panels, and walls	50%
Floor	30%

The control cab's CU is estimated by the following procedure:

a. The cavity ratios are:

(1) Ceiling Cavity Ratio = 0

(2) Room Cavity Ratio = $\frac{5h_{RC}\ (\text{room length} + \text{room width})}{\text{room length} \times \text{room width}}$

$$RCR = \frac{5\ (43.5)\ (134 + 76)}{134\ (76)}$$

$$RCR = 4.49$$

(3) Floor Cavity Ratio = $RCR\ \frac{h_{FC}}{h_{RC}}$

$$FCR = 4.49\ \frac{30}{43.5} = 3.09$$

b. From the above Ceiling and Floor Cavity Ratios and Figure 9-3 in Appendix A, the effective cavity reflectances are:

(1) Effective Ceiling Cavity Reflectance = 80%

(2) Effective Floor Cavity Reflectance = 22%

c. Now the approximate CU can be obtained from Figure 9-4 in Appendix A. For luminaire distribution number 7,* the CU for 50 percent Wall Reflectance, 80 percent effective Ceiling Cavity Reflectance, and an RCR of 4.49, lies between 0.48 and 0.54. Interpolating, the CU = 0.51.

d. The data in Figure 9-4 of Appendix A are based on a 20 percent effective Floor Cavity Reflectance; since the shelter's effective Floor Cavity Reflectance is close to 20 percent, it is not necessary to modify the CU as it would be if the effective Floor Cavity reflectances were much different from 20 percent. Figure 9-5 in Appendix A gives correction factors for effective Floor Cavity reflectances other than 20 percent.

The LLD and LDD Factors for the Control Cab Lighting System are determined as follows:

a. Since there must be a capability for dimming the fluorescent lighting system, type 48 T-12 430 ma, Rapid Start lamps are required. From Figure 9-6 in Appendix A, the LLD Factor for this lamp (cool white color) is 0.86, assuming 12 hours of operation per start.

b. Since luminaire distribution number 7 (Fig. 9-4, Appendix A) specified an LDD category 5, the LDD is determined from category 5 data of Figure 9-7, Appendix A. The shelter interior's dirt environment is considered clean; therefore, the LDD factor for cleaning the luminaire and shelter surface annually is 0.88.

Given the CU, LLD and LDD factors, equation (5) indicates how many lamp lumens will be required to maintain an illumination level of 100 footcandles.

$$\text{Lamp Lumens} = \frac{\text{maintained footcandles} \times \text{empty shelter workplane area}}{\text{CU} \times \text{LLD} \times \text{LDD}}$$

$$\text{Lamp Lumens} = \frac{100 \times 70.6}{0.51 \times 0.86 \times 0.88} = \frac{7060}{0.386}$$

$$\text{Lamp Lumens} = 18300$$

Since a type 48 T-12 rapid-start fluorescent lamp, cool white color, generates 3100 lumens initially, the shelter's lighting system will require six lamps.

* This type of luminaire was selected because it transmits and distributes light so efficiently. Its coefficients of utilization are the highest of any fluorescent luminaire illustrated in Figure 9-4, Appendix A.

The initial illumination level is calculated from equation (3):

$$\text{Footcandles} = \frac{\text{lamp lumens x CU}}{\text{area}}$$

$$\text{Footcandles} = \frac{6\ (3100)\ (0.51)}{70.6} = 134$$

It will not be possible to calculate luminance levels for interior surfaces by the method described in Part I, because the data of Figure 9-34, Appendix A,does not give luminance coefficients for this type of luminaire. As an alternative, luminance levels may be computed as described in the Third Edition of the IES Lighting Handbook (7):

a. Determine average interior workplane illumination.

b. Compute room coefficient, K_r

$$K_r = \frac{\text{wall area}}{4 \text{ x floor area}}$$

c. Refer to Figure 9-27, Appendix A, to obtain luminance factors corresponding to room reflectances and K_r. Interpolate when necessary.

d. Multiply the luminance factors by the average illumination in step a.

For this shelter, the calculations are as follows:

a. Average initial illumination = 134 footcandles.

b. Room coefficient, $K_r = \frac{214}{4\ (70.6)} = 0.76$

c. From Figure 9-27c, Appendix A, the luminance (brightness) factors are:

Wall -- 0.266

Ceiling -- 0.240

Floor -- 0.30

Ceiling, wall, and floor reflectances are 0.8, 0.5, and 0.3 respectively.

d. Wall luminance = 0.266 (134) = 35.6 foot-Lamberts

Ceiling luminance = 0.240 (134) = 32.2 foot-Lamberts

Floor luminance = 0.30 (134) = 40.2 foot-Lamberts

This completes the initial lighting estimates; final lighting calculations are made after a specific luminaire has been selected.

TABLE 7

ML-1A Control Cab Visual Tasks and Recommended Illumination Levels

Task	Illumination (footcandles)
1. Reading technical manuals	30-50
2. Making entries in the log	50
3. Preparing failure reports	50-70
4. Monitoring instrumentation (meters, etc.)	50
5. General electrical testing (using multimeters, scopes, etc.)	50-100
6. Using circuit diagrams	100
7. Soldering	100

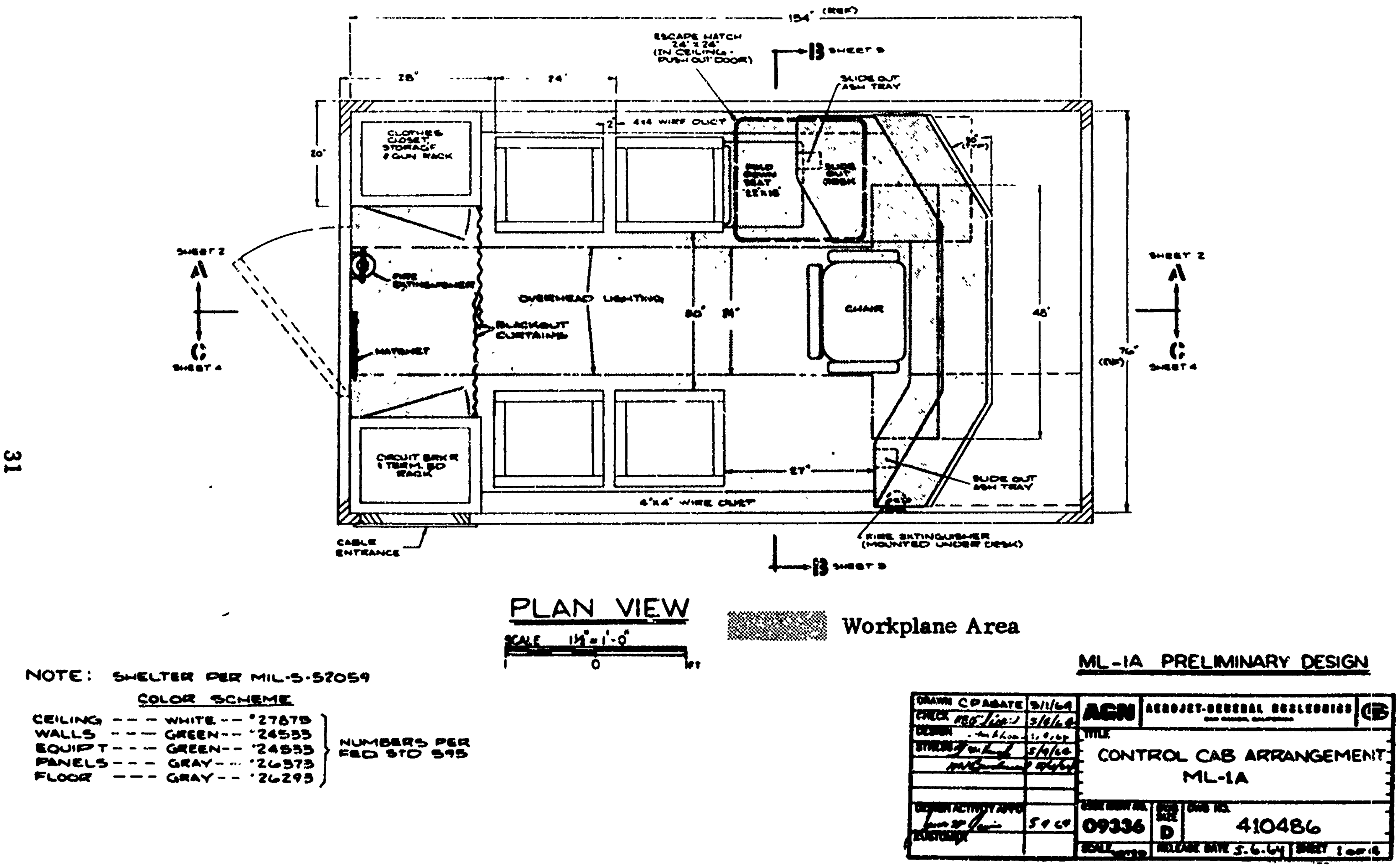
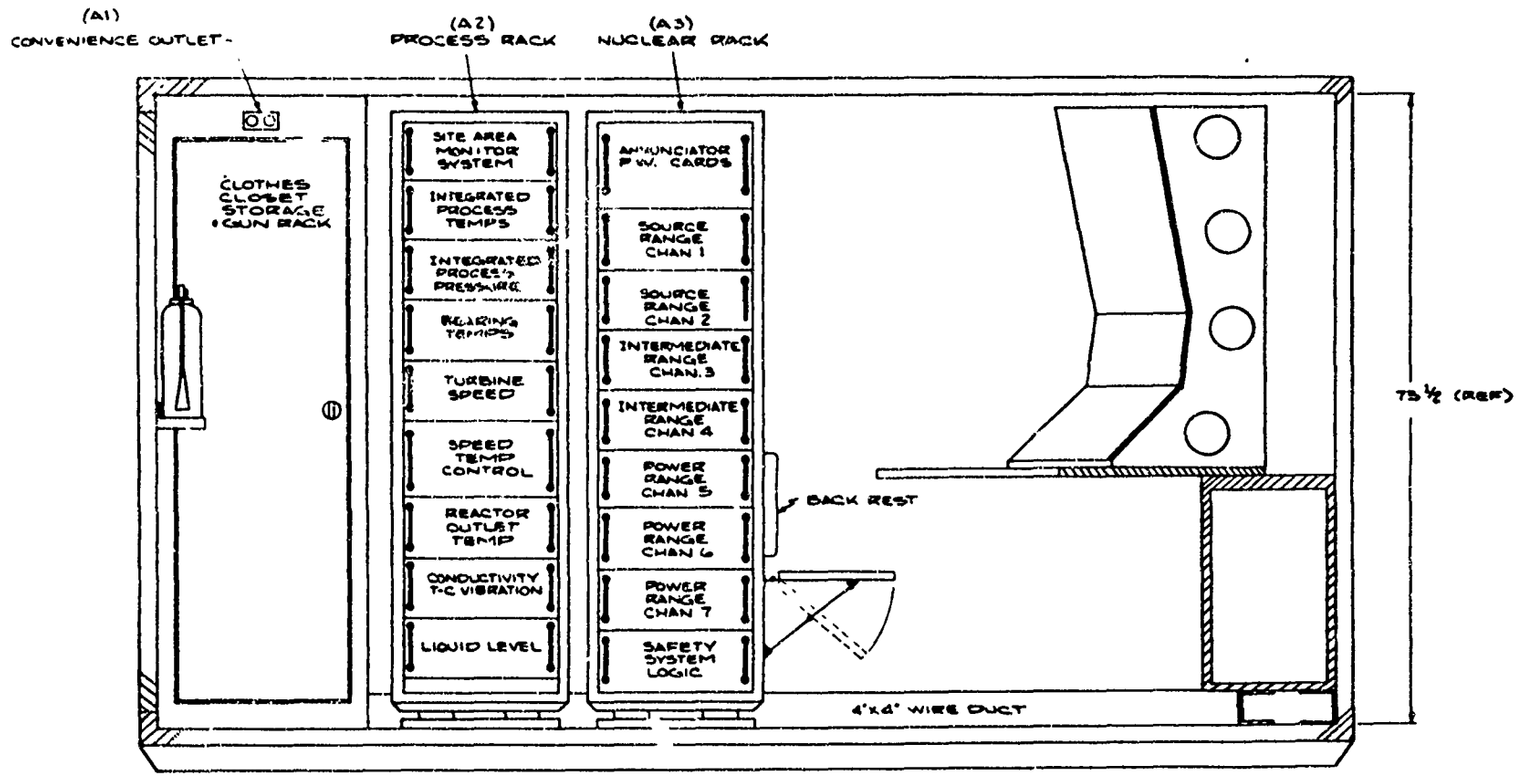


Fig. 3. PLAN VIEW OF ML-1A CONTROL CAB, SHOWING ACTUAL WORKPLANE AREA



SECTION A-A

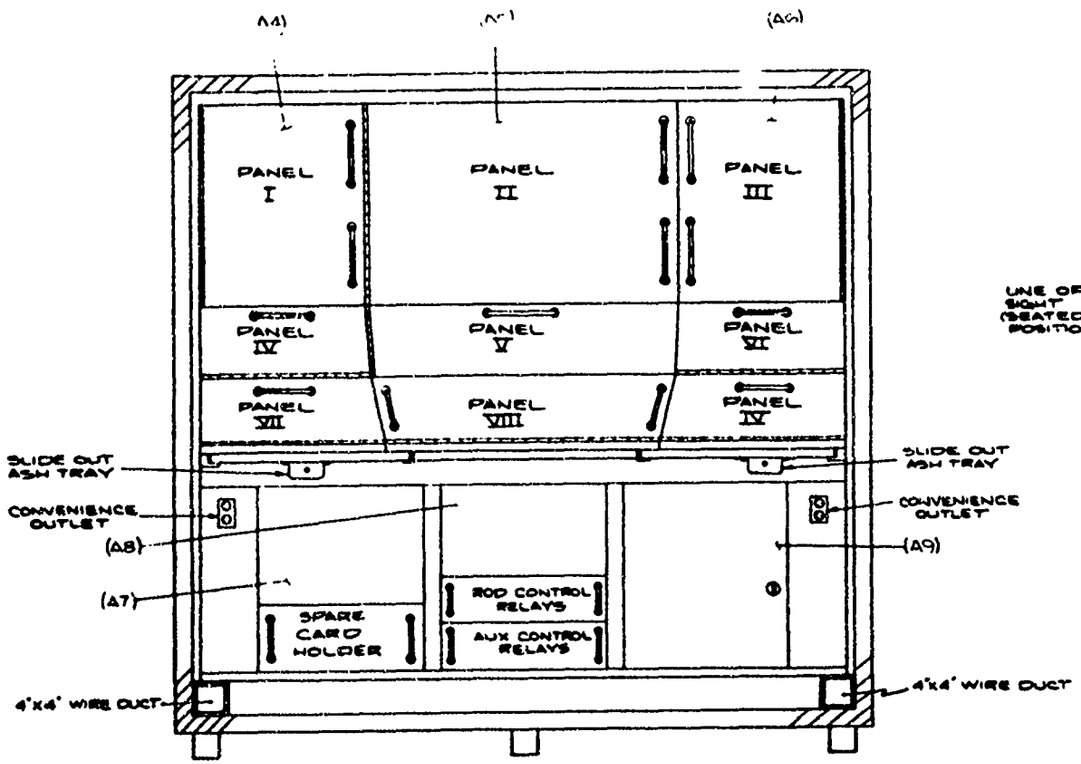
SCALE 1½" = 1'-0"

0 FT

ML-1A PRELIMINARY DESIGN

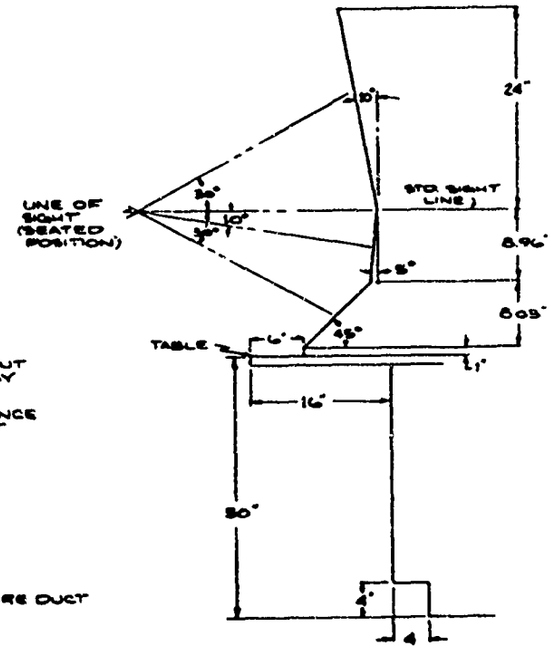
AGN	AEROJET-GENERAL NUCLEONICS	
TITLE: CONTROL CAB ARRANGEMENT ML-1A		
CODE IDENT NO. 09336	DWG SIZE D	DWG NO. 410486
SCALE NOTED	RELEASE DATE 5-6-64	SHEET 2 of 4

Fig. 4. LEFT-SIDE VIEW OF ML-1A CONTROL CAB



SECTION 13-13

SCALE 1½"=1'-0"

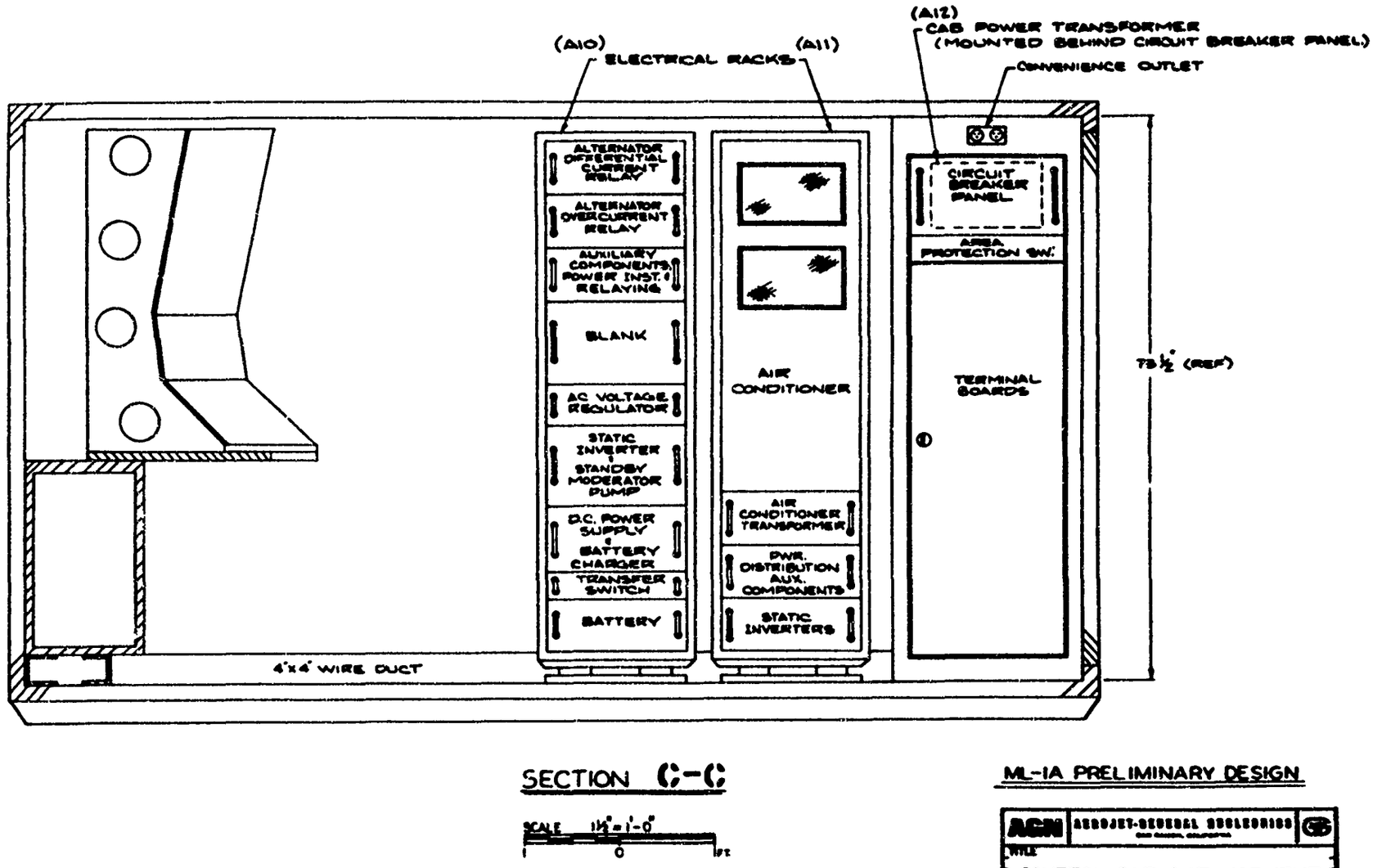


CONSOLE PROFILE

ML-1A PRELIMINARY DESIGN

AGN AEROJET-GENERAL NUCLEONICS		
TITLE: CONTROL CAB ARRANGEMENT ML-1A		
09336	D	DWG NO. 410486
SCALE	RELEASE DATE 5-6-64	SHEET 3 OF 4

Fig. 5. OPERATOR'S CONSOLE



SECTION C-C

SCALE 1½" = 1'-0"

ML-1A PRELIMINARY DESIGN

AGN	AEROJET-GENERAL NUCLEONICS	GE
TITLE: CONTROL CAB ARRANGEMENT ML-1A		
09336	SIZE D	410486
SCALE AS NOTED	RELEASE DATE 5-6-64	SHEET 4 of 4

Fig. 6. RIGHT-SIDE VIEW OF ML-1A CONTROL CAB

Lamp Layout

Figure 3 shows the ceiling area available for mounting lamps. This ceiling area permits only one reasonable lamp arrangement: two lamps in the operator area and perpendicular to the aisle, and two pairs of lamps paralleling the entire length of the aisle area and protruding into the operator area. The last two lamps contribute light to both operator and aisle areas. If there were no escape hatch, it would also be possible to arrange four lamps in the operator area perpendicular to two lamps in the aisle area.

Lighting Components

Reviewing the specifications of several commercially available components,* to determine which ones would meet the lighting requirements best, guided the designer's selection of components:

a. Aisle Area Luminaire -- Day-Brite #2x84 Chassis (one required)
Day-Brite #789P Lens (two required)

b. Operator Area Luminaire -- Day-Brite #1x42 Chassis (one required)
Day-Brite #739 Lens (one required)

c. Dimming System -- General Electric DS-5000 Fluorescent Dimming System -- refer to GE brochure #GEA-7874 for description and characteristics.

The Day-Brite luminaires are recessed into the cab ceiling to a maximum depth of 1 13/16 inches; however, the luminaire's depth is 3 1/4 inches, so 1 7/16 inches of each luminaire protrudes below the ceiling. This reduces the overall floor-to-ceiling height from 73 1/2 inches to approximately 73 inches, so personnel over six feet tall must enter and leave the cab cautiously. Increasing the interior floor-to-ceiling height of the cab to 76 inches would accommodate 95th percentile personnel.

* See Appendix B for other components considered.

Final Calculations

As stated in Part I, data for commercial luminaires may still give coefficients of utilization in terms of Room Index, rather than the Room Cavity Ratio, as is true with the Day-Brite Luminaires selected for the shelter lighting system. The Room Index for the shelter is calculated as follows:

a. From equation (8),

$$\text{Room Ratio} = \frac{\text{width x length}}{\text{Mounting height of luminaire above work plane} \times (\text{width} + \text{length})}$$

$$\text{Room Ratio} = \frac{(76)\quad(134)}{43.5\ (76 + 134)}$$

$$\text{Room Ratio} = \frac{10184}{9135} = 1.115$$

b. From Table 6, the Room Index for a Room Ratio of 1.115 is H. For a Room Index of H -- and with ceiling, wall, and floor reflectances of 80, 50, and 30 respectively -- the coefficient of utilization for the Day-Brite 789P and 739 Waffletex lens (diffuser) units is 0.47 (Appendix B).

The photometric data for the Day-Brite luminaires also give Maintenance Factors (MF) for three different conditions of environmental cleanliness. In place of the MF, the LLD and LDD Factors are preferred and are better indicators of light depreciation. The MF should be used only when the LLD and LDD factors cannot be computed. For this case, the product of the LLD and LDD factors is approximately 0.76, and the MF for a good condition is 0.75.

Using the above coefficient of utilization in equation (5), the lamp lumens required are:

$$\text{Lamp Lumens} = \frac{100 \times 70.6}{0.47 \times 0.86 \times 0.88} = \frac{7060}{.356}$$

$$\text{Lamp Lumens} = 19850$$

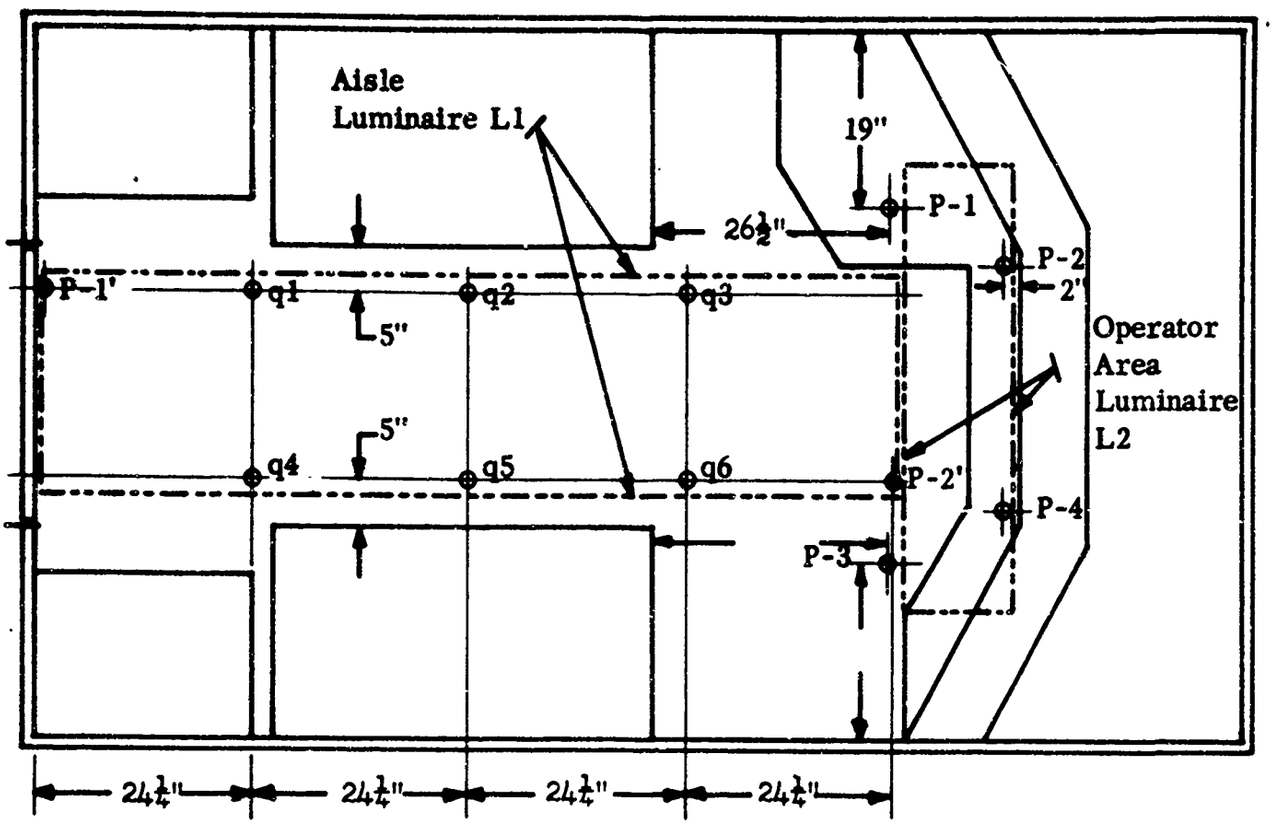
Theoretically, seven lamps will be required. However, seven lamps give an initial illumination level of 144 footcandles and a maintained illumination level of 110 footcandles, while six lamps will provide 124 initial and 93 maintained footcandles. Because seven lamps give more light than needed -- and because the tasks that require higher illumination levels are not done as often as reading, writing, and monitoring instruments -- six lamps (type 48 T-12 RS) are adequate for this application.

Initial luminance levels are:

Wall -- 0.266 (124) = 33 foot-Lamberts

Ceiling -- 0.240 (124) = 29.8 foot-Lamberts

Floor -- 0.30 (124) = 37.2 foot-Lamberts



Sta	fc	Sta	fc
q1	121	P-1'	91
q2	136	P-2'	142
q3	143		
q4	120		
q5	134		
q6	144		
Total	797	Total	233
Avg q =	133	Avg P' =	116

Sta	fc
P-1	122
P-2	130
P-3	121
P-4	131
Total	504
Avg P =	126

Sta	fc
X-1	122
X-2	129
X-3	120
X-4	130
Total	501
Avg X =	125

Avg X equals emergency illumination level with right half of L1 and all of L2 illuminated; points X-1 thru X-4 are same as points P-1 thru P-4.

$$\text{Average Illumination} = \frac{\left(\frac{qN + P'}{N + 1}\right) + P}{2}$$

(N = number of luminaires)

Average Illumination = 127 footcandles

Fig. 7. ML-1A MOCK-UP: ILLUMINATION LEVELS AND MEASUREMENT POINTS ON A WORKPLANE 30 INCHES ABOVE THE FLOOR

LIGHTING SURVEY

Method and Procedure

Components of the proposed AGN Lighting System for the ML-1A control cab were obtained and installed in a plywood control-cab mock-up (Figs. 1 and 2), and a lighting survey was performed to verify the lighting-system design.

Illumination was measured with a Weston Model 614 Footcandle Meter (cosine corrected). Measurements were made on a horizontal workplane 30 inches above the floor. The specific measurement points and calculations of average illumination are shown in Figure 7. These points are derived from Tables 5B and 5E of the IES publication How to Make a Lighting Survey (4). The survey was made with simulated equipment installed. It was felt that these illumination measurements should not differ greatly from measurements of an empty shelter, because the equipment's surface reflectance is about the same as that of the wall. Figure 3 shows that the equipment covers about 2/3 of the wall area. Also, light distribution would be somewhat poorer in an empty shelter, because the luminaire's location in the ceiling would not be centered longitudinally.

Illuminance measurements were made for the console panels, console displays, walls, ceiling and floor with a Photo Research Corp. Spectra Spot Brightness Meter, model #SB. Brightness values obtained from a target disk with known reflectance of better than 99 percent provided relative percent reflectances of these surfaces. The target disk was placed at the same locations where the brightness measurements had been taken. The specific measurement areas on the console are shown in Figures 9 through 16.

Both illumination and brightness measurements were made after approximately 100 hours of lamp operating time.

Results

The average illumination level on a horizontal workplane 30 inches above the floor, as measured in the ML-1A mock-up, was 127 footcandles with the dimmer control set for maximum illumination. (Figure 7 gives illumination levels measured at specific points and equations used to determine the average illumination.) The illumination values ranged from 92 to 144 footcandles.

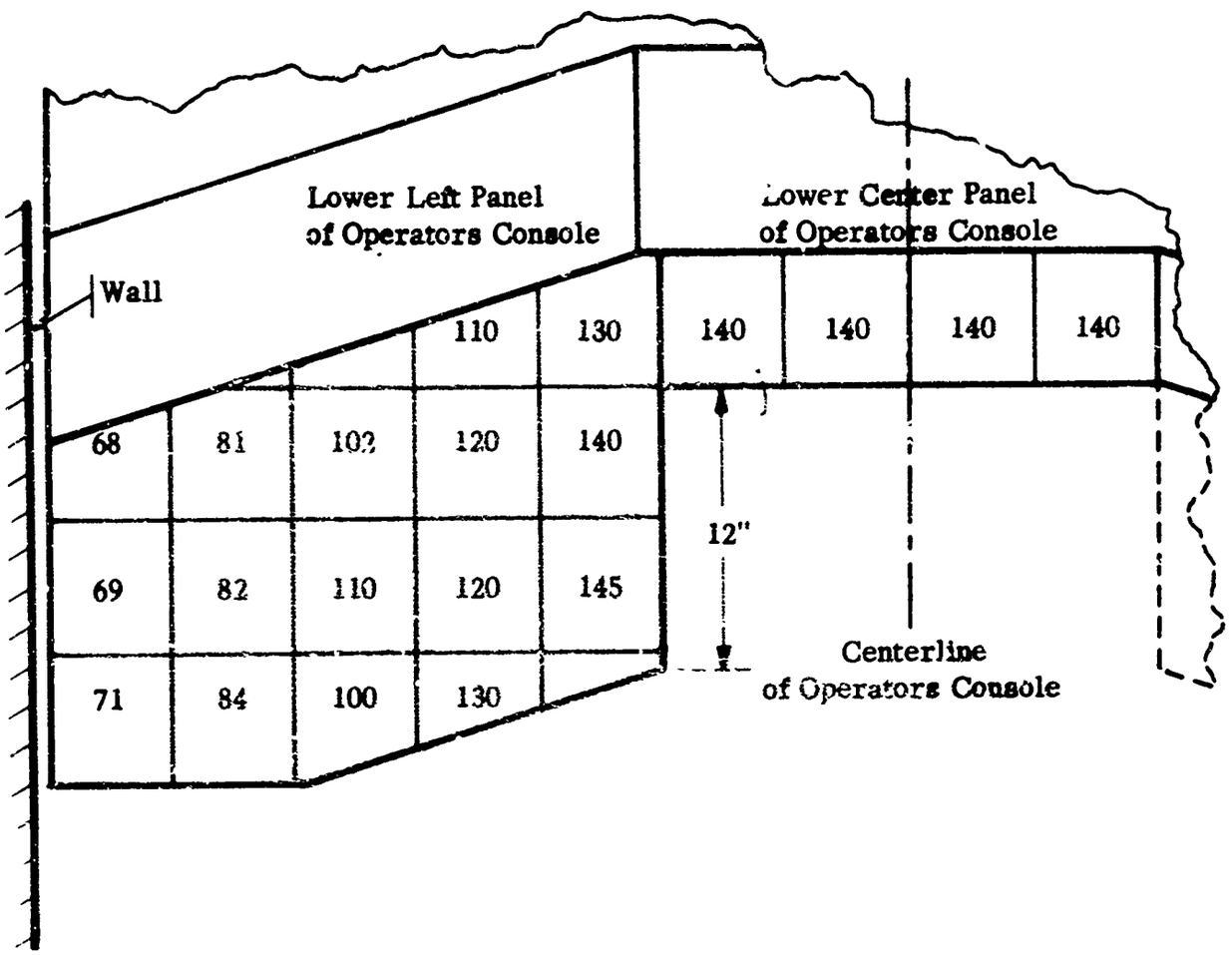


Fig. 8. ILLUMINATION LEVELS MEASURED ON LEFT PULL-OUT DESK AND CENTER DESK OF OPERATOR'S CONSOLE
(Values are in footcandles)

Illumination levels on the floor directly below measurement points q1 through q6 were:

q1 -- 80 footcandles

q2 -- 100 footcandles

q3 -- 98 footcandles

q4 -- 85 footcandles

q5 -- 100 footcandles

q6 -- 98 footcandles

Illumination levels on the left pullout-desk and center-desk areas of the console are shown in Figure 8.

Illumination levels on the floor under the console desk were:

center section -- 30 footcandles

left section -- 26 footcandles

right section -- 28 footcandles

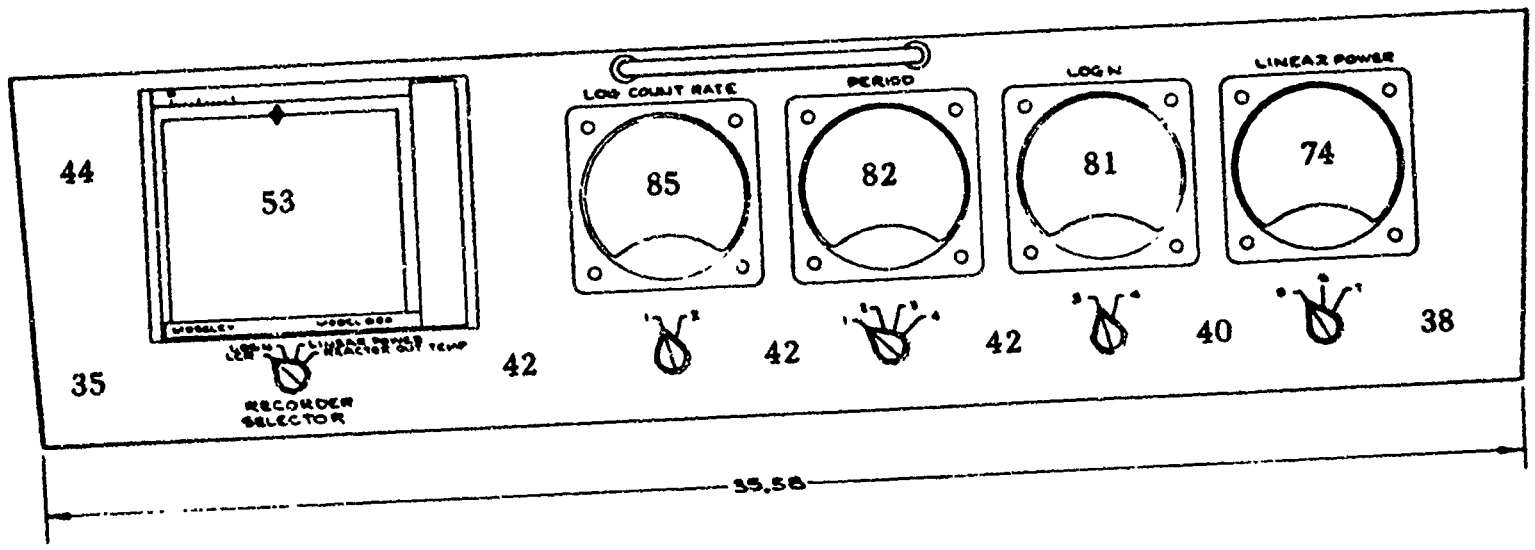
The floor readings were taken at three points on a line parallel with and located eight inches from the lower vertical console panels.

Figures 9 through 16 show brightness levels for the console surfaces and displays. Table 8 gives brightness levels and percent reflectances for ceiling, walls, work surfaces (desk), floor, center console surfaces and center console displays.

Table 9 shows the measured reflectances for the surfaces and the recommended reflectance range (criteria) for these surfaces.

Table 10 shows calculated and measured brightness levels of the ceiling, walls and floor. Direct glare from the ambient lighting system caused no problem; however, glare from the aisle luminaire was reflected from the meter lenses of the lower-center console panel, where it would be visible to a seated operator.

The uniformity of illumination was, for the most part, adequate, but the minimum illumination level was approximately four percent below the recommended one-sixth value below the average illumination level. No lamp flicker was observed.



SCALE 6"-1'-0"

ML-1A PRELIMINARY DESIGN

DRAWN K. Knowles	5/1/66	AGPI	GENERAL DYNAMICS
CHECK W.E. Wright	5/6/66	TITLE	PANEL ASSEMBLY - CONSOLE CENTER CENTER - ML-1A PANEL V
DESIGN L. L'Amie	5/9/66		
STRESS M.N. Smith	5-9-66		
DESIGN ACTIVITY APPD	5-9-66	CODE IDENT. NO. 09336	DWG SIZE D
CUSTOMER		SCALE NONE	DWG NO. 410491
		RELEASE DATE 5-6-66	SHEET 1 OF 1

Fig. 9. LUMINANCE LEVELS MEASURED ON CONSOLE PANEL -- MIDDLE-CENTER
(Values are in foot-Lamberts)

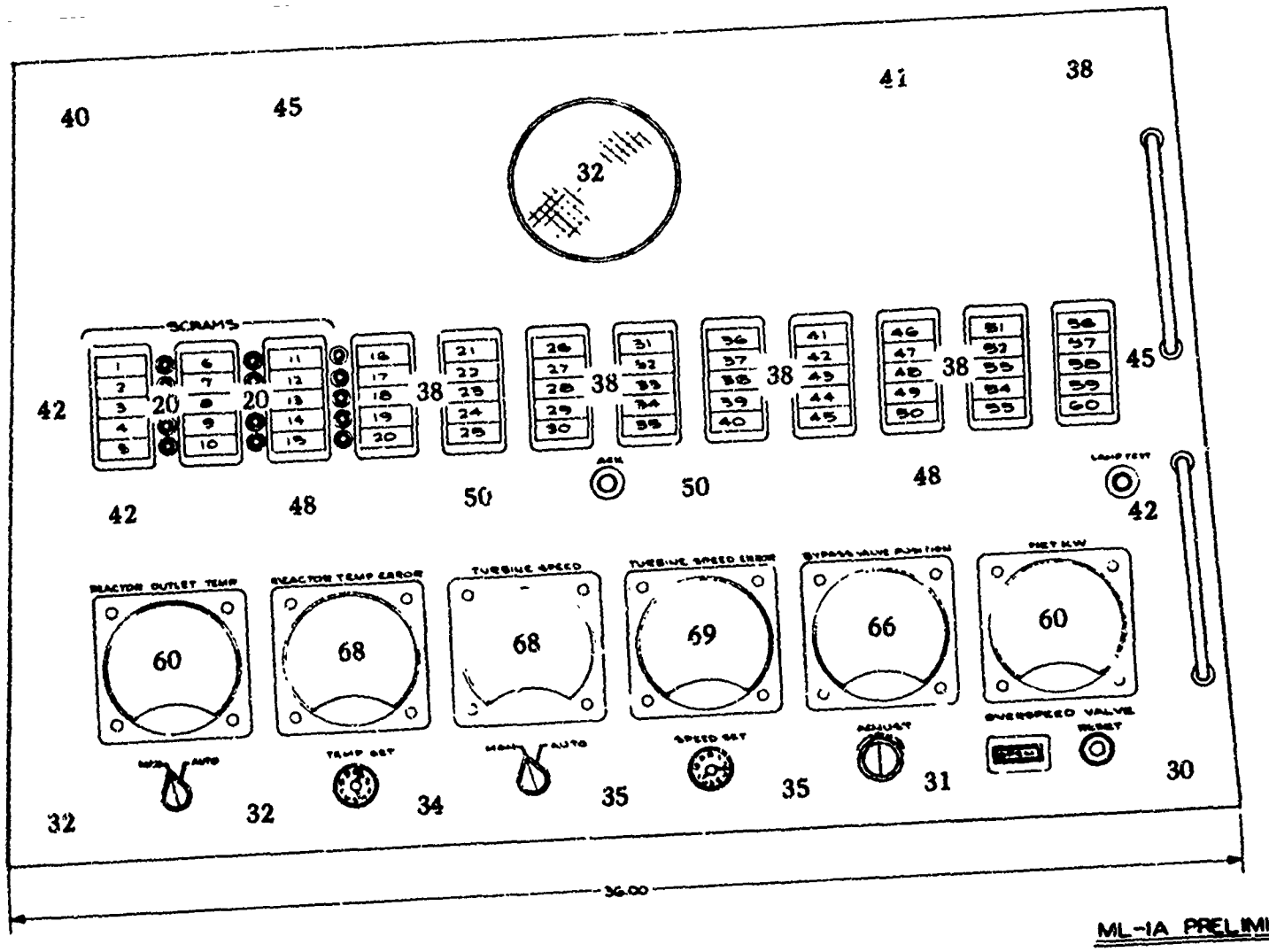
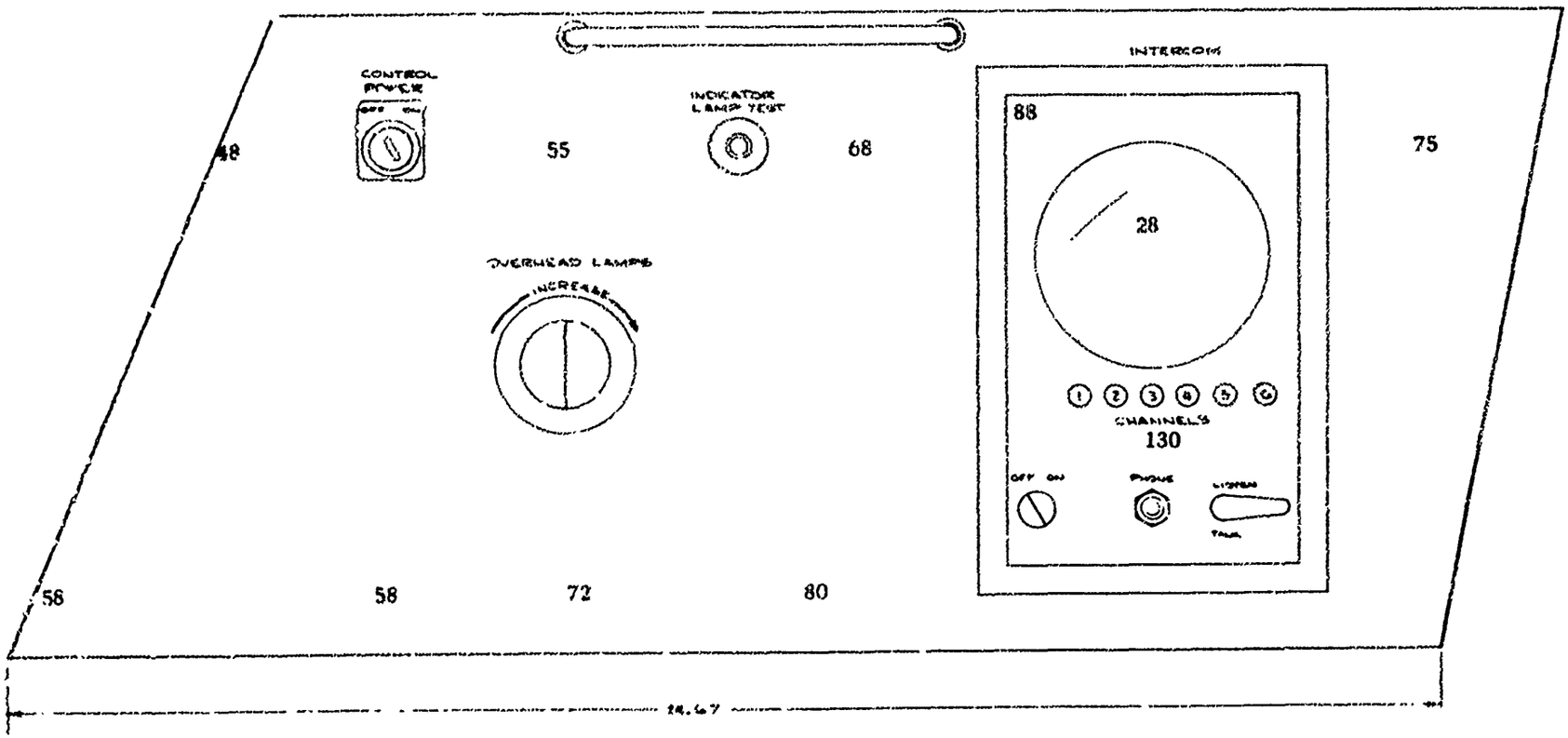


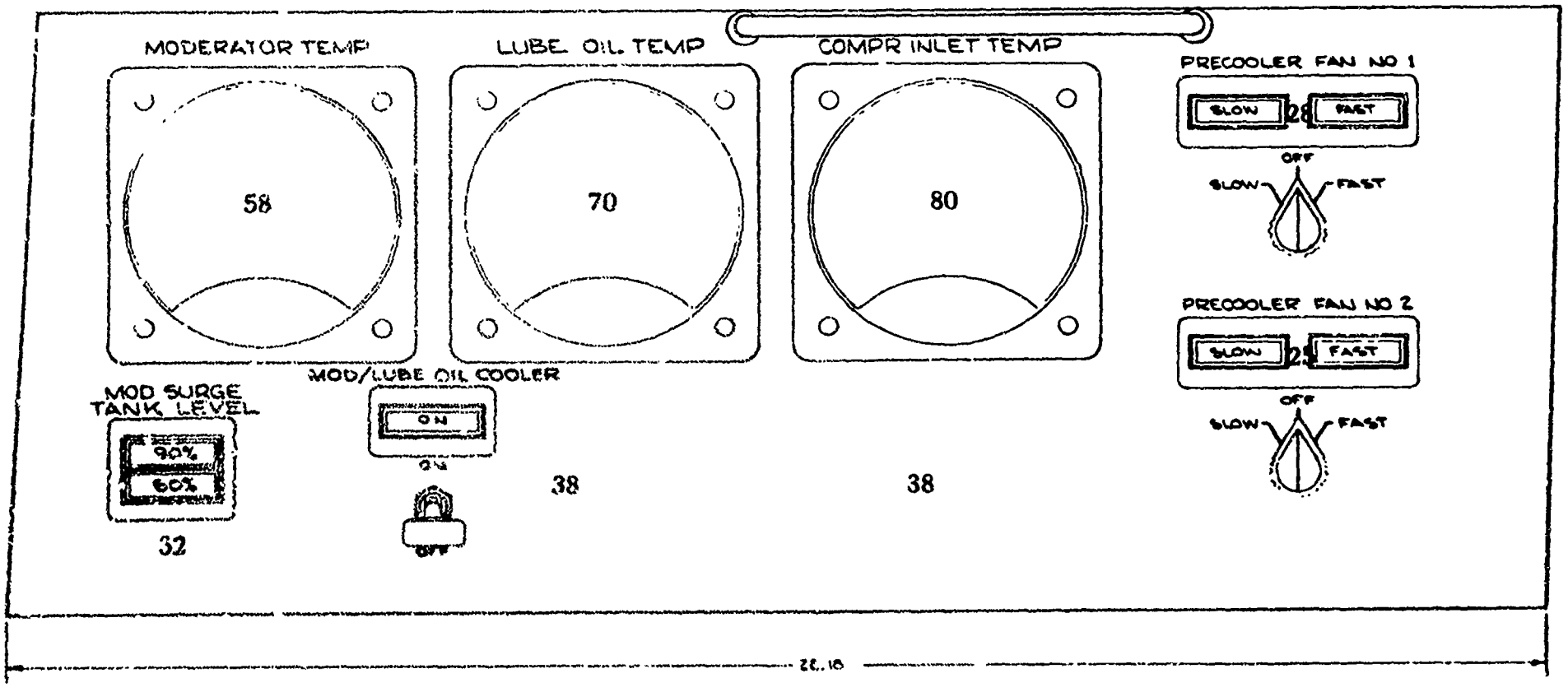
Fig. 10. LUMINANCE LEVELS MEASURED ON CONSOLE PANEL -- UPPER-CENTER
(Values are in foot-Lamberts)



ML-1A PRELIMINARY DESIGN

DRAWN Kuo-Hua	5/6/64	AGM	ASSOCIATED GENERAL ROOSEVELT
CHECK	5/6/64	TITLE	PANEL ASSEMBLY - CONSOLE-LEFT HAND LOWER - ML-1A PANEL VII
DESIGN	5/6/64		
STRESS	5/6/64		
	5/6/64		
DESIGN ACTIVITY APPD	5/6/64	CODE IDENT NO. 09336	DWG SIZE D DWG NO. 410493
CUSTOMER		SCALE none	RELEASE DATE 5.6.64 SHEET 1 OF 1

Fig. 11. LUMINANCE LEVELS MEASURED ON CONSOLE PANEL -- LOWER-LEFT
(Values are in foot-Lamberts)



Scale 12"-1'-0"
0 1 2 3m

ML-1A PRELIMINARY DESIGN

DRAWN		AGC	AEROJET-GENERAL NUCLEONICS
CHECK		TITLE	PANEL ASSEMBLY- CONSOLE-LEFT HAND CENTER- ML-1A PANEL III
DESIGN		CODE IDENT NO. 09336	SIZE D
ENGINEER		DWG NO. 410490	
DESIGN ACTIVITY APPD		SCALE	RELEASE DATE 5.6.64
CUSTOMER			SHEET 1 OF 1

Fig. 12. LUMINANCE LEVELS MEASURED ON CONSOLE PANEL -- MIDDLE-LEFT
(Values are in foot-Lamberts)

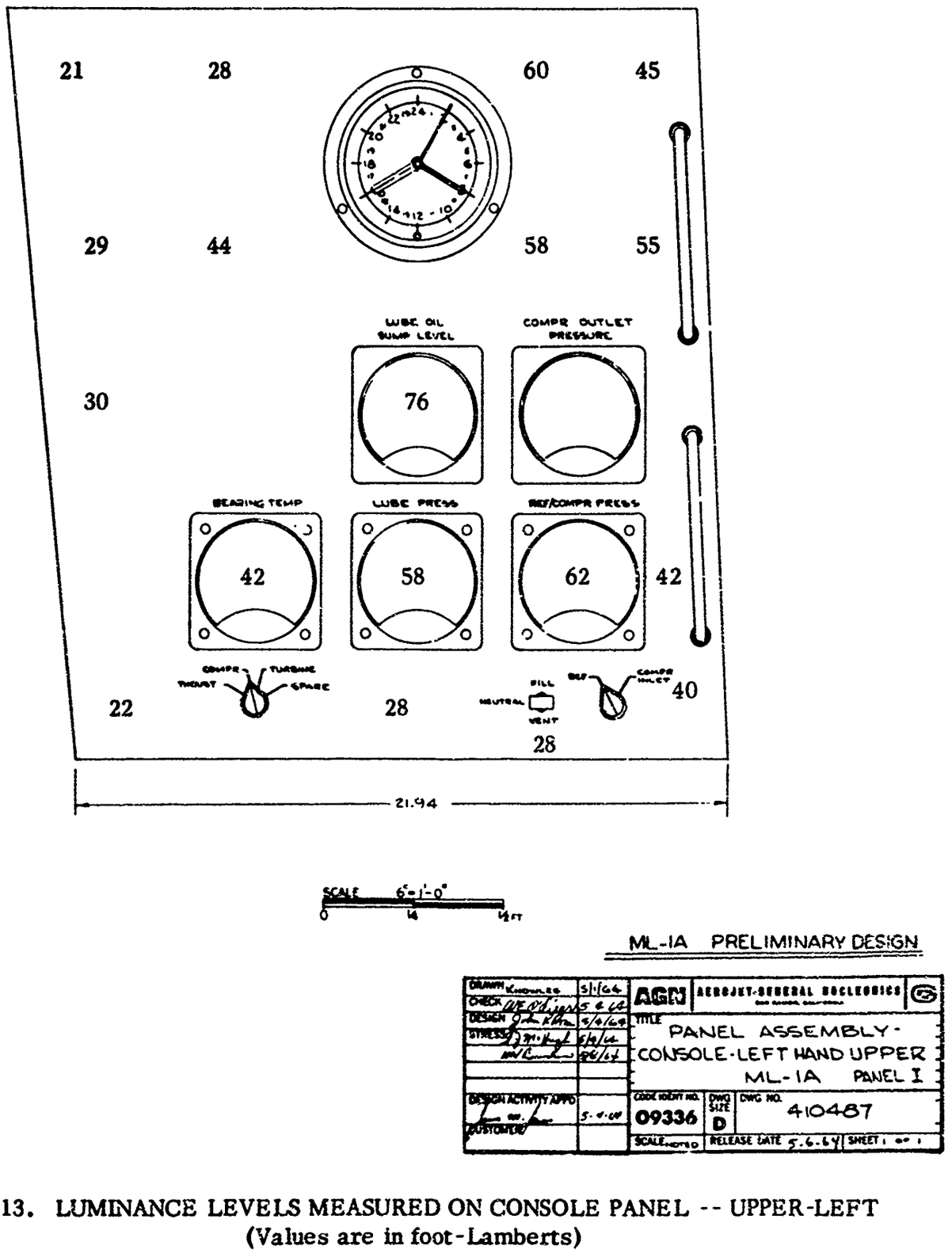
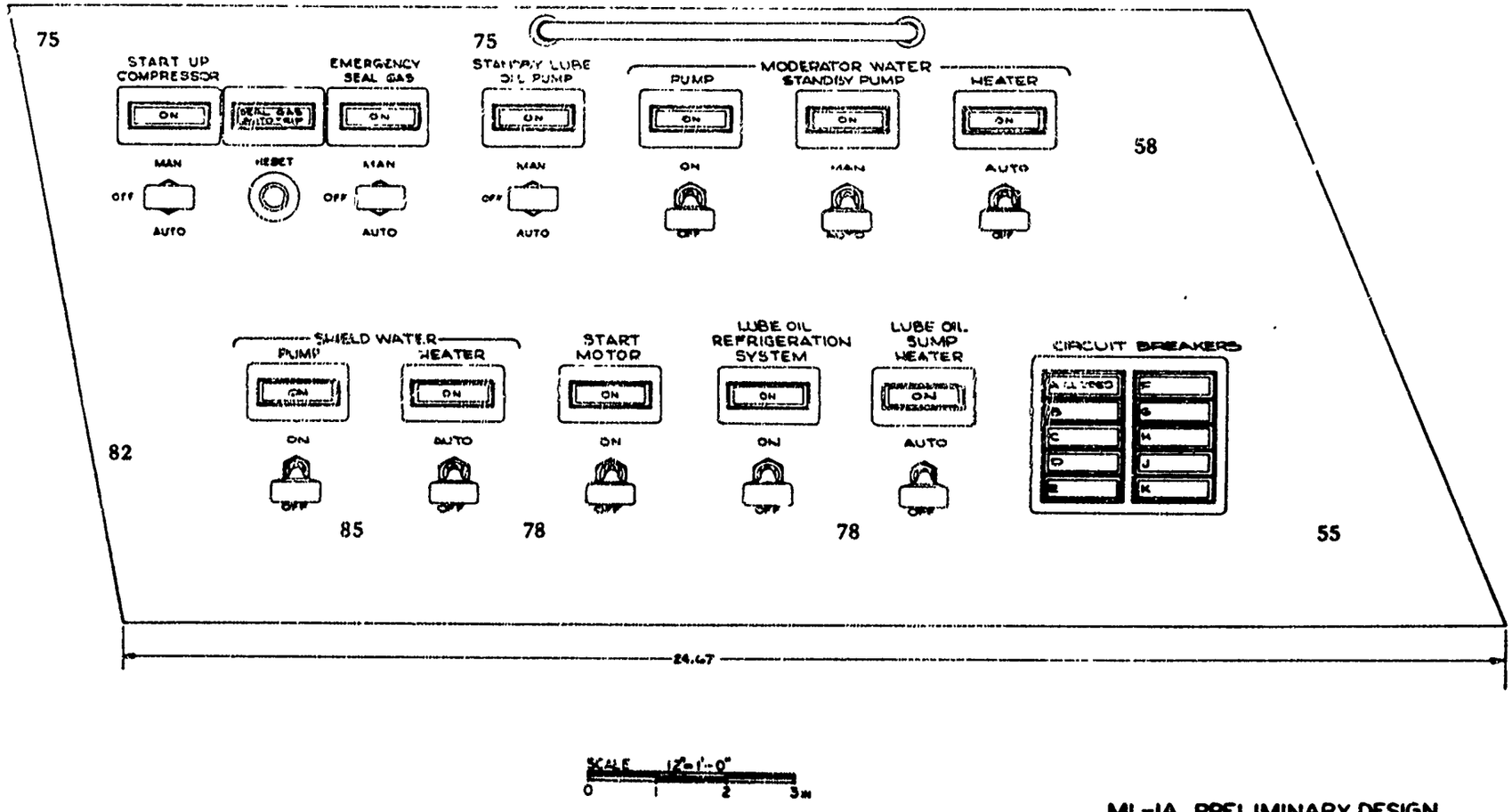


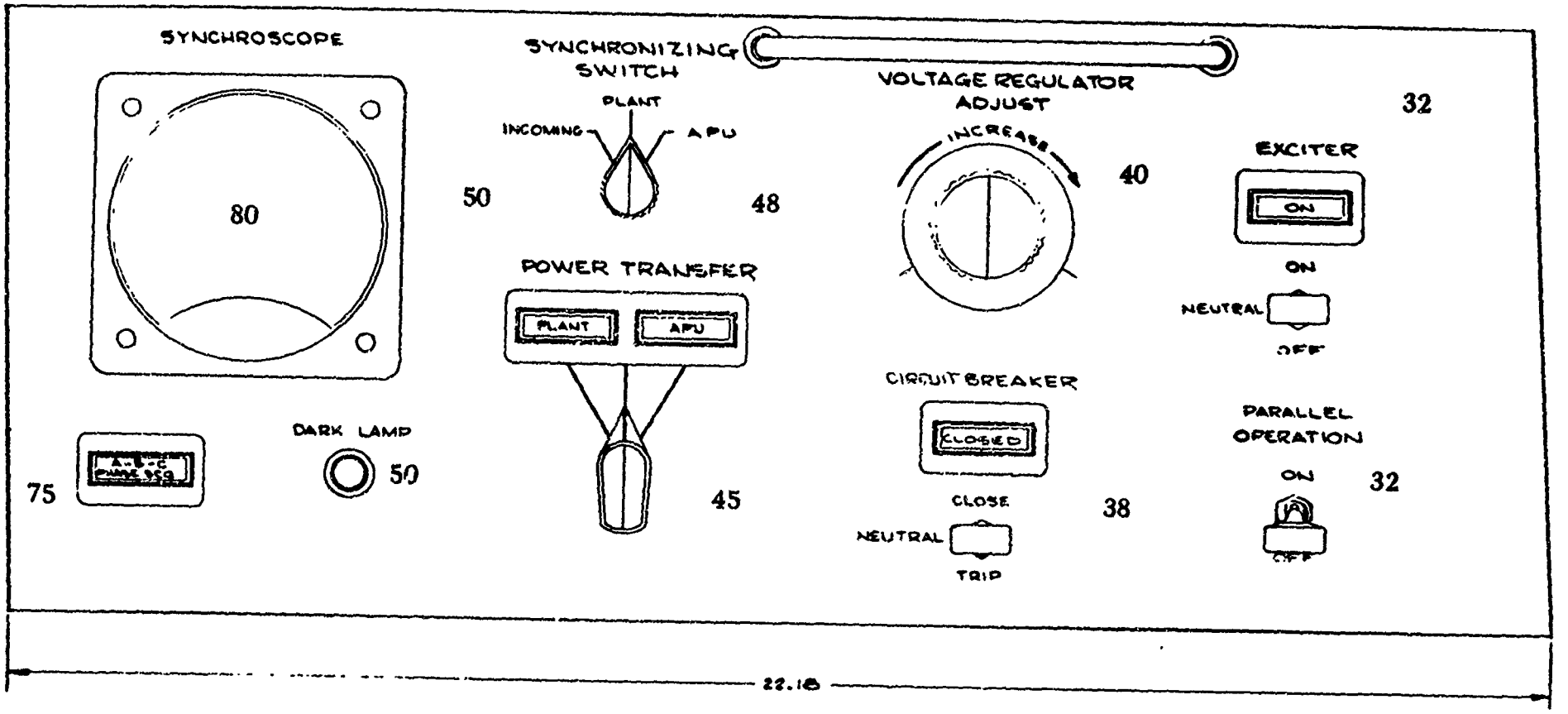
Fig. 13. LUMINANCE LEVELS MEASURED ON CONSOLE PANEL -- UPPER-LEFT
(Values are in foot-Lamberts)



ML-IA PRELIMINARY DESIGN

DRAWN		5/6/64	AGN AEROJET-GENERAL NUCLEONICS
CHECK		5/6/64	
DESIGN		5/6/64	TITLE PANEL ASSEMBLY- CONSOLE-RIGHT HAND LOWER- ML-IA PANEL IX
STRESS		5/6/64	
		5/6/64	
DESIGN ACTIVITY APPR.		5-6-64	CODE IDENT NO. 09336 / SIZE D / DWG NO. 410495
CUSTOMER			SCALE NONE / RELEASE DATE 5-6-64 / SHEET 1 OF 1

Fig. 14. LUMINANCE LEVELS MEASURED ON CONSOLE PANEL -- LOWER-RIGHT
(Values are in foot-Lamberts)

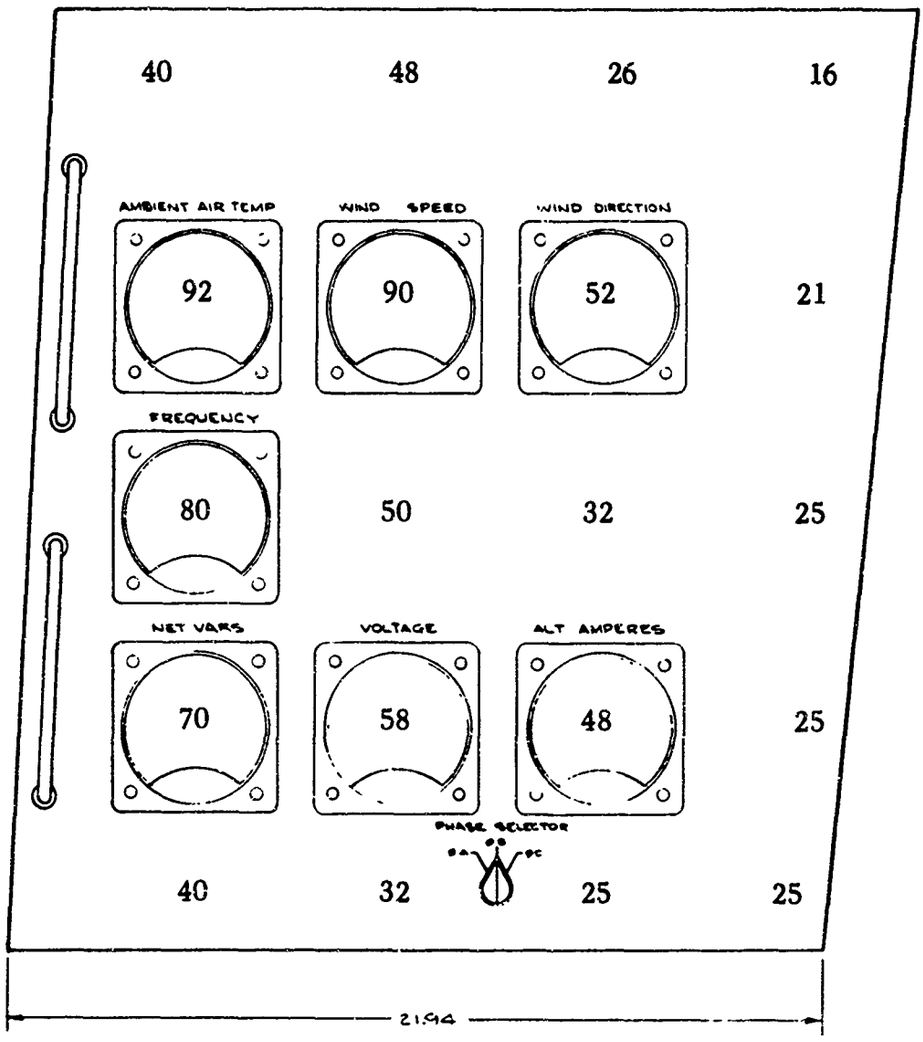


SCALE 12"=1'-0"
0 1 2 3M

ML-IA PRELIMINARY DESIGN

DRAWN	5/6/64	AGN	AEROJET-GENERAL NUCLEONICS
CHECK	5/6/64	TITLE	PANEL ASSEMBLY-CONSOLE-RIGHT HAND CENTER ML-IA PANEL VI
DESIGN	5/6/64		
STRESS	5/6/64		
	5/6/64		
DESIGN ACTIVITY APPD	5-6-64	CODE IDENT NO. 09336	DWG SIZE D
CUSTOMER		DWG NO. 410492	
		SCALE NOTED	RELEASE DATE 5.6.64 SHEET 1 OF 1

Fig. 15. LUMINANCE LEVELS MEASURED ON CONSOLE PANEL -- MIDDLE-RIGHT
(Values are in foot-Lamberts)



ML-IA PRELIMINARY DESIGN

SCALE 6"-1'-0"
0 1/4 1/2 FT

DRAWN Knowles	5/11/64	AGN AEROJET-GENERAL NUCLEONICS	
CHECK	5/6/64	TITLE PANEL ASSEMBLY- CONSOLE RIGHT HAND UPPER ML-1A PANEL III	
DESIGN	5/6/64		
STRESS	5/6/64		
	5/4/64		
DESIGN ACTIVITY APPD		CODE IDENT NO. 09336	DWG SIZE D
CUSTOMER		DWG NO. 410489	
		SCALE AS NOTED	RELEASE DATE 5-6-64 SHEET 1 of 1

Fig. 16. LUMINANCE LEVELS MEASURED ON CONSOLE PANEL -- UPPER-RIGHT
(Values are in foot-Lamberts)

TABLE 8

ML-1A Control Cab Mock-Up Interior Surface Reflectances and Luminance Levels

Surface	Disk Luminance (foot-Lamberts)	Surface Luminance (foot-Lamberts)	Percent Reflectance
Ceiling (center of escape hatch)	35	30	86
Walls (on vertical centerline of cab door -- 8 inches below luminaire)	150	90	60
(30 inches above floor)	60	33	55
Console (left desk)	135	58	43
Work Surfaces (center desk)	140	65	46
Upper Center Console Panel[a]	110	50	45
	110	42	38
	148	80	54
Upper Center Console Displays	110	68	62
	110	85	77
	148	115	78
Floor (measurement point q1)	80	22	27

TABLE 9

ML-1A Control Cab Mock-Up Interior Surface Reflectances

and Recommended Surface-Reflectance Criteria

Surface	Measured Percent Reflectance[a]	Percent Reflectance Criteria[b]
Ceiling	86	80 to 90
Wall	55	40 to 60
Console Work Surface	46	25 to 45
Center Console Panel	45	25 to 45
Center Console Display	62	Not more than 75 for 25 percent panel reflectance
Floor	27	Not less than 20

[a] Values from Table 8

[b] Values from Tables 2 and 3

TABLE 10

Calculated and Measured Luminance Levels

Surface	Calculated Luminance	Measured Luminance (from Table 8)
Ceiling	36	30
Wall	33	30
Floor	30	22

Discussion

The average illumination level measured in the ML-1A mock-up compares favorably to the calculated value. Substituting values in Equation (2) and setting the LLD and LDD factors equal to unity,* the calculated illumination is:

$$\text{Footcandles} = \frac{(\text{total lamp lumens})\ (CU)\ (LLD)\ (LDD)}{\text{Area of Workplane}} = \frac{(18600)\ (0.47)\ (1)}{70.6}$$

$$\text{Footcandles} = 124$$

The measured illumination is 127 footcandles, and the percent error is:

$$\text{Percent Error} = \frac{127 - 124}{127}\ (100) = 3.2\%$$

The error probably results mainly from the small differences between the theoretical and actual reflectances of the interior surfaces -- the CU is based on standard surface reflectances. For example, the measured wall reflectance is 55 percent, and the theoretical wall reflectance, on which the CU is based, is 50 percent. Floor and ceiling reflectances differ similarly:

	Measured Reflectance	CU Standard Reflectance
Floor	27%	30%
Ceiling	86%	80%

From these values it is apparent that the illumination measured in the mock-up should be slightly higher than the theoretical value of illumination. Since ceiling and wall reflectances affect the average workplane illumination level much more than the floor reflectance does, the fact that the actual floor's reflectance varies slightly from the standard reflectance usually has no significant effect on the illumination level.

Multiplying the measured initial illumination level (127 footcandles) by the LLD and LDD factors gives a predicted illumination level just before a scheduled maintenance period of 96 footcandles. The lighting system therefore essentially satisfies the in-service illumination-level requirement of 100 footcandles.

* Because the luminaires are new and clean, the MF, LLD, and LDD factors equal unity.

Luminance levels of the walls, ceiling and floor compared favorably with the calculated levels given in Table 10. Where they differed, it was probably because an approximate wall area was used instead of the actual wall area -- actual wall area is generally difficult to obtain where equipment such as the console does not present a completely vertical surface -- and because the data in Figure 9-27c, Appendix A, are based on standard ceiling, wall and floor reflectances, rather than on the actual reflectances in the mock-up.

Among the luminance levels of the console surfaces and displays (Figs. 9 through 16) only one exceeded the maximum recommended luminance ratios in Table 3. The 3:1 ratio between a task area and adjacent darker surroundings is exceeded if the luminance levels of the extreme upper-left and upper-right console surfaces are compared with luminance levels of the lower-center console surfaces. Since these extreme upper surfaces are beyond the effective lighting distribution pattern of the luminaire, they may be considered in the C environmental classification, instead of the B environmental classification. The 5:1 ratio therefore applies, and the luminance difference of this area is satisfactory.

For the most part, the measured surface reflectances are within the recommended ranges of surface reflectances (Table 9). The only surface which does not comply with the recommended reflectance is the console work surface; but, because this reflectance value is almost within the recommended reflectance range, the surface should not cause operator discomfort or fatigue.

Using diffusing lenses in the console meters eliminated the reflected specular glare of the aisle luminaire.

Conclusions

1. The lighting system proposed by AGN provides the required levels of illumination for the various visual tasks performed in the ML-1A control cab.

2. Contrast ratios (luminance ratios) between the visual task area and other surfaces are satisfactory.

3. Sources of reflected glare were eliminated.

4. The floor-to-ceiling height of the shelter should be increased 2 1/2 inches.

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APPENDIX A

LIGHTING-DESIGN DATA*

* Appendix A is reproduced from the 4th Edition of the IES Lighting Handbook (8), except Figure 9-27 which is reproduced from the 3rd Edition of the IES Lighting Handbook (7).

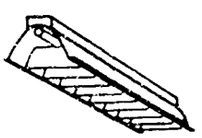
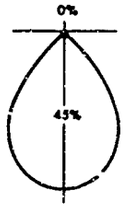
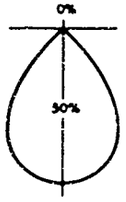
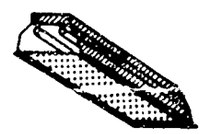
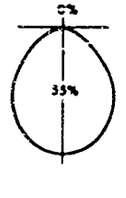
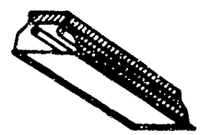
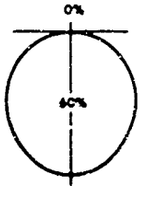
Fig. 9-3 Per Cent Effective Ceiling or Floor Cavity Reflectance for Various Reflectance Combinations

Ceiling or Floor Cavity Ratio	Per Cent Ceiling or Floor Reflectance	90				80				70			50				30			10		
	Per Cent Wall Reflectance	90	70	50	30	80	70	50	30	70	50	30	70	50	30	65	50	30	10	50	30	10
	0	90	90	90	90	80	80	80	80	70	70	70	50	50	50	30	30	30	30	10	10	10
	0.1	90	89	88	87	79	79	78	78	69	69	68	50	49	48	30	30	29	29	10	10	10
	0.2	89	88	86	85	79	78	77	76	68	67	66	49	48	47	30	29	29	28	10	10	9
	0.3	89	87	85	83	78	77	75	74	68	66	64	49	47	46	30	29	28	27	10	10	9
	0.4	88	86	83	81	78	76	74	72	67	65	63	48	46	45	30	29	27	26	11	10	9
	0.5	88	85	81	78	77	75	73	70	66	64	61	48	46	44	29	28	27	25	11	10	9
	0.6	88	84	80	76	77	75	71	68	65	62	59	47	45	43	29	28	26	25	11	10	9
	0.7	88	83	78	74	76	74	70	66	65	61	58	47	44	42	29	28	26	24	11	10	8
	0.8	87	82	77	73	75	73	69	65	64	60	56	47	43	41	29	27	25	23	11	10	8
	0.9	87	81	76	71	75	72	68	63	63	59	55	46	43	40	29	27	25	22	11	9	8
	1.0	86	80	74	69	74	71	66	61	63	58	53	46	42	39	29	27	24	22	11	9	8
	1.1	86	79	73	67	74	71	65	60	62	57	52	46	41	38	29	26	24	21	11	9	8
	1.2	86	78	72	65	73	70	64	58	61	56	50	45	41	37	29	26	23	20	12	9	7
	1.3	85	78	70	64	73	69	63	57	61	55	49	45	40	36	29	26	23	20	12	9	7
	1.4	85	77	69	62	72	68	62	55	60	54	48	45	40	35	28	26	22	19	12	9	7
	1.5	85	76	68	61	72	68	61	54	59	53	47	44	39	34	28	25	22	18	12	9	7
	1.6	85	75	66	59	71	67	60	53	59	52	45	44	39	33	28	25	21	18	12	9	7
	1.7	84	74	65	58	71	66	59	52	58	51	44	44	38	32	28	25	21	17	12	9	7
	1.8	84	73	64	56	70	65	58	50	57	50	43	43	37	32	28	25	21	17	12	9	6
	1.9	84	73	63	55	70	65	57	49	57	49	42	43	37	31	28	25	20	16	12	9	6
	2.0	83	72	62	53	69	64	56	48	56	48	41	43	37	30	28	24	20	16	12	9	6
	2.1	83	71	61	52	69	63	55	47	56	47	40	43	36	29	28	24	20	16	13	9	6
	2.2	83	70	60	51	68	63	54	45	55	46	39	42	36	29	28	24	19	15	13	9	6
	2.3	83	69	59	50	68	62	53	44	54	46	38	42	35	28	28	24	19	15	13	9	6
	2.4	82	68	58	48	67	61	52	43	54	45	37	42	35	27	28	24	19	14	13	9	6
	2.5	82	68	57	47	67	61	51	42	53	44	36	41	34	27	27	23	18	14	13	9	6
	2.6	82	67	56	46	66	60	50	41	53	43	35	41	34	26	27	23	18	13	13	9	5
	2.7	82	66	55	45	66	60	49	40	52	43	34	41	33	26	27	23	18	13	13	9	5
	2.8	81	66	54	44	66	59	48	39	52	42	33	41	33	25	27	23	18	13	13	9	5
	2.9	81	65	53	43	65	58	48	38	51	41	33	40	33	25	27	23	17	12	13	9	5
	3.0	81	64	52	42	65	58	47	38	51	40	32	40	32	24	27	22	17	12	13	8	5
	3.1	80	64	51	41	64	57	46	37	50	40	31	40	32	24	27	22	17	12	13	8	5
	3.2	80	63	50	40	64	57	45	36	50	39	30	40	31	23	27	22	16	11	13	8	5
	3.3	80	62	49	39	64	56	44	35	49	39	30	39	31	23	27	22	16	11	13	8	5
	3.4	80	62	48	38	63	56	44	34	49	38	29	39	31	22	27	22	16	11	13	8	5
	3.5	79	61	48	37	63	55	43	33	48	38	29	39	30	22	26	22	16	11	13	8	5
	3.6	79	60	47	36	62	54	42	33	48	37	28	39	30	21	26	21	15	10	13	8	5
	3.7	79	60	46	35	62	54	42	32	48	37	27	38	30	21	26	21	15	10	13	8	4
	3.8	79	59	45	35	62	53	41	31	47	36	27	38	29	21	26	21	15	10	13	8	4
	3.9	78	59	45	34	61	53	40	30	47	36	26	38	29	20	26	21	15	10	13	8	4
	4.0	78	58	44	33	61	52	40	30	46	35	26	38	29	20	26	21	15	9	13	8	4
	4.1	78	57	43	32	60	52	39	29	46	35	25	37	28	20	26	21	14	9	13	8	4
	4.2	78	57	43	32	60	51	39	29	46	34	25	37	28	19	26	20	14	9	13	8	4
	4.3	78	56	42	31	60	51	38	28	45	34	25	37	28	19	26	20	14	9	13	8	4
	4.4	77	56	41	30	59	51	38	28	45	34	24	37	27	19	26	20	14	8	13	8	4
	4.5	77	55	41	30	59	50	37	27	45	33	24	37	27	19	25	20	14	8	14	8	4
	4.6	77	55	40	29	59	50	37	26	44	33	24	36	27	18	25	20	14	8	14	8	4
	4.7	77	54	40	29	58	49	36	26	44	33	23	36	26	18	25	20	13	8	14	8	4
	4.8	76	54	39	28	58	49	36	25	44	32	23	36	26	18	25	19	13	8	14	8	4
	4.9	76	53	38	28	58	49	35	25	44	32	23	36	26	18	25	19	13	7	14	8	4
	5.0	76	53	38	27	57	48	35	25	43	32	22	36	26	17	25	19	13	7	14	8	4

Fig. 9–4. Coefficients of Utilization for Typical Luminaires with Suggested Maximum Spacing Ratios and Maintenance Category

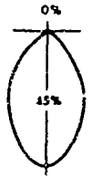
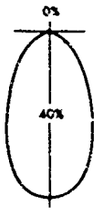
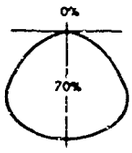
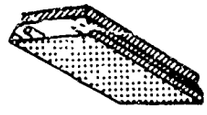
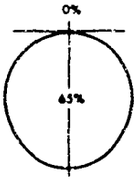
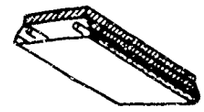
To obtain a Coefficient of Utilization (see also Fig. A-19):

1. Determine Cavity Ratios for the Room, Ceiling, and Floor from Fig. 9–2 or the formulas on page 9–2.
2. Determine the Effective Ceiling and Floor Cavity Reflectances from Fig. 9–3. Use expected *maintained* ceiling, floor, and wall reflectances unless *initial* illumination is desired.
3. Obtain Coefficient of Utilization (CU) for 20 per cent Effective Floor Cavity Reflectance from appropriate table below for luminaire type to be used. Interpolate, when necessary, to obtain CU for exact Room Cavity Ratio for nearest Effective Ceiling Cavity Reflectances above and below reflectance obtained in Step 2, interpolate between these CU's to obtain CU for Step 2 Ceiling Cavity Reflectance.
4. If Effective Floor Cavity Reflectance differs significantly from 20 per cent, obtain multiplier from Fig. 9–6 and apply this to the CU obtained in Step 3.

Typical Distribution and Maximum Spacing[a]	ρ_{cc}[c] →	80			70			50			30			10			0	Typical Luminaires and Luminaire Maintenance Category[e]
	ρ_w[d] →	50	30	10	50	30	10	50	30	10	50	30	10	50	30	10	0	
	RCR[b] ↓	Coefficients of Utilization for 20 Per Cent Effective Floor Cavity Reflectance, ρ_{FC}																
1	1	.49	.48	.47	.48	.47	.46	.47	.46	.45	.45	.44	.44	.43	.43	.42	.41	
	2	.45	.43	.41	.44	.42	.40	.43	.41	.40	.42	.40	.39	.40	.39	.38	.37	
	3	.42	.39	.37	.41	.39	.37	.40	.38	.36	.39	.37	.36	.38	.36	.35	.34	
	4	.38	.35	.33	.38	.35	.33	.37	.34	.33	.36	.34	.32	.35	.33	.32	.31	
	5	.35	.32	.30	.35	.32	.30	.34	.31	.29	.33	.31	.29	.32	.30	.29	.28	
	6	.33	.30	.27	.32	.29	.27	.32	.29	.27	.31	.29	.27	.30	.28	.27	.26	
	7	.30	.27	.25	.30	.27	.25	.29	.26	.25	.29	.26	.24	.28	.26	.24	.24	1500 mA, 1-lamp, 1'-wide aluminum troffer with 45° x 45° shielding
	8	.28	.25	.22	.27	.25	.22	.27	.24	.22	.26	.24	.22	.26	.24	.22	.21	
	9	.25	.22	.20	.25	.22	.20	.25	.22	.20	.24	.22	.20	.24	.21	.20	.19	
Max. S/MH$_{wp}$ = 1.1	10	.23	.20	.18	.23	.20	.18	.23	.20	.18	.22	.20	.18	.22	.20	.18	.17	LDD Maint. Category IV
2	1	.54	.52	.50	.53	.51	.49	.50	.49	.48	.49	.47	.46	.47	.46	.45	.44	
	2	.49	.46	.44	.48	.46	.43	.46	.45	.43	.45	.43	.42	.43	.42	.41	.40	
	3	.45	.42	.39	.44	.41	.39	.43	.40	.38	.42	.40	.38	.40	.39	.37	.36	
	4	.41	.37	.35	.40	.37	.35	.39	.36	.34	.38	.36	.34	.37	.35	.33	.32	
	5	.37	.34	.31	.37	.34	.31	.36	.33	.30	.35	.32	.30	.34	.32	.30	.29	
	6	.34	.31	.28	.34	.30	.28	.33	.30	.28	.32	.30	.27	.32	.29	.27	.26	
	7	.31	.28	.25	.31	.28	.25	.30	.27	.25	.30	.27	.25	.29	.26	.25	.24	2-lamp (T12), 1'-wide aluminum troffer with 45° x 30° shielding
	8	.29	.25	.22	.28	.25	.22	.28	.25	.22	.27	.24	.22	.26	.24	.22	.21	
	9	.26	.22	.20	.26	.22	.20	.25	.22	.20	.25	.22	.20	.24	.21	.20	.19	
Max. S/MH$_{wp}$ = 1.1	10	.24	.20	.18	.24	.20	.18	.23	.20	.18	.23	.20	.18	.23	.20	.18	.18	LDD Maint. Category IV
3	1	.73	.70	.68	.70	.68	.66	.66	.64	.62	.61	.60	.59	.57	.56	.55	.53	
	2	.65	.61	.58	.63	.60	.57	.59	.56	.54	.56	.53	.51	.52	.50	.49	.47	
	3	.59	.54	.50	.57	.53	.49	.54	.50	.47	.50	.48	.45	.48	.45	.43	.42	
	4	.53	.48	.45	.51	.47	.43	.49	.45	.41	.46	.42	.40	.43	.41	.38	.37	
	5	.47	.42	.38	.46	.41	.37	.44	.39	.36	.41	.38	.35	.39	.36	.34	.32	
	6	.43	.38	.34	.42	.37	.33	.40	.35	.32	.38	.34	.31	.36	.33	.30	.28	
	7	.39	.33	.29	.38	.33	.29	.36	.31	.28	.34	.30	.27	.32	.29	.27	.25	
	8	.35	.30	.26	.34	.29	.26	.32	.28	.25	.31	.27	.24	.29	.26	.23	.22	2-lamp, 1'-wide, white troffer with prismatic lens
	9	.31	.26	.22	.31	.26	.22	.29	.25	.22	.28	.24	.21	.26	.23	.20	.19	
Max S/MH$_{wp}$ = 1.2	10	.29	.23	.20	.28	.23	.20	.27	.22	.19	.25	.21	.19	.24	.21	.18	.17	LDD Maint. Category V
4	1	.63	.60	.58	.62	.59	.57	.59	.57	.56	.57	.55	.54	.55	.53	.52	.51	
	2	.55	.51	.48	.54	.50	.47	.52	.49	.46	.50	.48	.45	.48	.46	.44	.43	
	3	.49	.44	.40	.48	.43	.40	.46	.42	.39	.44	.41	.39	.43	.40	.38	.37	
	4	.44	.38	.35	.43	.38	.34	.41	.37	.34	.40	.36	.33	.39	.36	.33	.32	
	5	.38	.33	.29	.38	.33	.29	.36	.32	.29	.35	.31	.28	.34	.31	.28	.27	
	6	.34	.29	.25	.34	.29	.25	.33	.28	.25	.32	.28	.25	.31	.27	.25	.23	
	7	.31	.26	.22	.30	.26	.22	.30	.25	.22	.29	.25	.22	.28	.24	.22	.20	
	8	.28	.22	.19	.27	.22	.19	.27	.22	.19	.26	.22	.19	.25	.21	.19	.17	2-lamp, 1'-wide white troffer with translucent diffuser
	9	.25	.20	.16	.25	.20	.16	.24	.19	.16	.23	.19	.16	.22	.19	.16	.15	
Max. S/MH$_{wp}$ = 1.2	10	.23	.18	.14	.22	.18	.14	.22	.17	.14	.21	.17	.14	.20	.17	.14	.13	LDD Maint. Category V

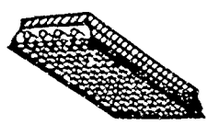
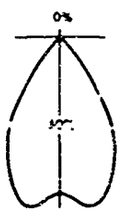
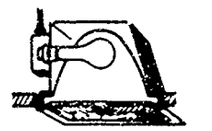
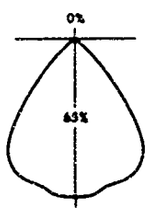
[a] Ratio of maximum spacing between luminaire centers to mounting (or ceiling) height above the work plane. See "Luminaire Spacing" on page 9-16.
[b] RCR = Room Cavity Ratio.
[c] ρ_{CC} = Per cent effective ceiling cavity reflectance.
[d] ρ_W = Per cent wall reflectance.
[e] See pages 9-16 and 9-17.

Fig. 9–4. *Continued*

Typical Distribution and Maximum Spacing[a]	ρ_{CC}[c] →	80			70			50			30			10			0	Typical Luminaires and Luminaire Maintenance Category[a]
	ρ_w[d] →	50	30	10	50	30	10	50	30	10	50	30	10	50	30	10	0	
	RCR[b] ↓	Coefficients of Utilization for 20 Per Cent Effective Floor Cavity Reflectance, ρ_{FC}																
5																		
	1	48	47	46	47	46	45	46	44	43	44	43	42	42	41	41	40	
	2	43	41	.39	42	40	38	41	39	37	40	38	37	38	37	36	35	
	3	39	36	.34	39	36	34	37	35	33	36	34	33	35	33	32	31	
	4	36	32	30	35	32	30	34	31	29	33	31	29	32	30	28	27	
	5	32	28	26	31	28	26	30	28	25	30	27	25	29	27	25	24	
	6	29	26	23	29	25	23	28	25	23	27	25	23	27	24	22	22	
	7	27	23	21	26	23	21	26	23	21	25	22	20	25	22	20	20	
	8	24	21	18	24	21	18	23	20	18	23	20	18	22	20	18	17	2-lamp, 1′-wide white troffer with 45° plastic louver
Max. $S/MH_{w_p} = 1.1$	9	22	19	16	22	18	16	21	18	16	21	18	16	20	18	16	15	
	10	20	17	15	20	17	15	20	17	15	19	16	15	19	16	14	14	LDD Maint Category IV
6																		
	1	44	42	.41	43	.41	.40	41	40	39	39	.39	.38	38	38	.37	36	
	2	39	38	36	39	37	35	37	36	34	36	35	34	35	34	33	32	
	3	36	33	31	35	33	31	34	32	31	33	32	30	32	31	30	29	
	4	33	30	29	32	30	28	31	29	27	30	28	27	30	28	27	26	
	5	30	27	25	29	26	24	28	26	24	28	26	24	27	25	24	23	
	6	27	24	22	27	24	22	26	24	22	26	23	22	25	23	22	21	
	7	25	22	20	25	22	20	24	22	20	24	21	20	23	21	20	19	2-lamp, 1′-wide white troffer with 45° white metal louvers
	8	23	20	18	23	20	18	22	20	18	22	19	18	21	19	18	17	
Max. $S/MH_{w_p} = 0.9$	9	21	18	16	21	18	16	20	18	16	20	17	16	19	17	16	15	
	10	19	16	14	19	16	14	19	16	14	18	16	14	18	16	14	14	LDD Maint Category IV
7																		
	1	.75	.72	70	73	71	69	70	68	67	68	.66	65	65	.64	.63	.62	
	2	67	63	59	65	62	59	63	60	57	61	58	56	59	57	55	54	
	3	60	55	51	59	54	51	57	53	50	55	52	49	53	50	48	47	
	4	54	48	44	53	48	44	51	47	43	50	46	43	48	45	42	41	
	5	48	42	38	47	42	38	46	41	37	44	40	37	43	39	36	35	
	6	43	37	33	42	37	33	41	36	33	40	36	32	39	35	32	31	
	7	39	33	29	38	33	29	37	32	28	36	31	28	35	31	28	27	2-lamp, 2′-wide white troffer with prismatic lens. (Multiply 0.9 for 4-lamp)
	8	35	29	25	34	29	25	33	28	25	32	28	25	32	28	24	23	
	9	31	25	21	31	25	21	30	24	21	29	24	21	28	24	21	20	
Max. $S/MH_{w_p} = 1.3$	10	28	23	19	28	22	19	27	22	19	26	22	19	26	22	19	17	LDD Maint Category V
8																		
	1	69	66	64	67	65	63	65	63	61	62	61	58	59	58	57	55	
	2	61	56	53	56	55	52	56	53	51	54	52	50	52	50	49	47	
	3	53	49	44	52	48	43	50	47	43	49	44	42	46	43	41	40	
	4	48	42	38	46	41	38	44	40	37	43	39	36	42	38	36	35	
	5	42	36	31	41	36	31	40	34	31	38	33	30	37	33	30	29	
	6	38	31	27	37	31	26	36	30	26	34	30	26	33	29	25	25	
	7	33	28	24	33	28	24	32	27	24	31	27	24	30	26	23	22	
	8	30	25	21	30	25	21	29	24	21	28	24	21	27	23	20	19	2-lamp, 2′-wide white troffer with translucent diffuser. (Multiply by 0.9 for 4-lamp)
	9	27	22	18	27	22	17	26	21	17	25	21	17	24	21	17	16	
Max. $S/MH_{w_p} = 1.2$	10	25	19	16	24	19	16	24	18	15	23	18	15	22	18	15	14	LDD Maint. Category V

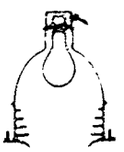
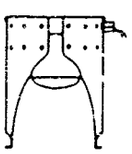
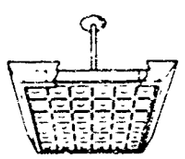
[a] Ratio of maximum spacing between luminaire centers to mounting (or ceiling) height above the work plane. See "Luminaire Spacing" on page 9-16.
[b] RCR = Room Cavity Ratio.
[c] ρ_{CC} = Per cent effective ceiling cavity reflectance.
[d] ρ_W = Per cent wall reflectance
[e] See pages 9-16 and 9-17

Fig. 9-4 Continued

Typical Distribution and Maximum Spacing[a]	ρ_{cc}[c] →	80			70			50			30			10			0	Typical Luminaires and Luminaire Maintenance Category[e]
	ρ_w[d] →	50	30	10	50	30	10	50	30	10	50	30	10	50	30	10	0	
	RCR[b] ↓	Coefficients of Utilization for 20 Per Cent Effective Floor Cavity Reflectance, ρ_{FC}																
9	1	.59	57	56	58	.56	.55	56	54	53	53	52	51	51	.51	.50	.49	
	2	.53	50	47	52	49	.47	50	48	46	48	46	.45	47	45	44	.43	
	3	48	.44	.41	47	.43	.40	.45	42	40	44	41	.39	.42	40	.39	.38	
	4	.43	.39	36	42	39	.36	41	.38	35	40	37	.35	39	.36	.34	33	
	5	.39	.34	31	.38	.34	.31	37	.33	31	36	33	30	35	.32	.30	29	
	6	35	.31	28	.35	31	.28	34	30	.27	.33	30	27	.32	.29	.27	.26	2-lamp, 2'-wide white troffer with 45° plastic louver. (Multiply by 0.95 for 4-lamp)
	7	.32	28	25	32	.28	25	31	27	.25	30	27	.24	29	27	.24	.23	
	8	.29	25	22	.29	25	22	28	.24	.22	27	24	22	.27	.24	.21	20	
	9	.26	22	.19	.26	22	.19	26	22	19	25	21	19	24	21	19	.18	
Max. S/MH_{wp} = 1.1	10	24	20	.17	24	20	17	23	20	.17	23	20	17	22	.19	.17	16	LDD Maint Category IV
10	1	.49	.47	46	.48	46	.45	46	45	44	44	43	42	42	.42	.41	.40	
	2	.44	.42	.40	43	.41	.39	.42	.40	.38	40	39	.38	.39	38	37	.36	
	3	.40	.37	35	39	37	35	.38	.36	.34	37	35	.34	36	34	.33	32	
	4	.37	.33	.31	36	.33	.31	35	.32	30	34	32	.30	33	.31	.30	.29	
	5	33	.30	.27	33	.29	27	32	29	27	31	28	27	.30	28	26	.25	
	6	.30	.27	.25	.30	.27	24	.29	.26	.24	28	26	.24	.28	26	.24	.23	
	7	.28	.25	.22	28	24	22	27	.24	.22	26	24	.22	.26	24	.22	.21	
	8	.25	.22	21	.25	.22	.21	25	.22	21	24	21	.19	24	21	.19	.19	4-lamp, 2'-wide white troffer with 45° white metal louver
	9	.23	.19	.18	.23	.19	18	22	.19	.18	22	.19	17	22	.19	.17	.17	
Max. S/MH_{wp} = 0.9	10	.21	.18	.16	.21	18	.16	21	.18	16	20	.18	.16	.20	.17	16	.15	LDD Maint Category IV
11	1	66	.65	63	.64	63	62	62	61	.60	60	59	.58	.58	.57	.57	.55	
	2	.61	.59	.56	61	.58	55	58	.56	54	56	55	.53	.55	53	52	.51	
	3	57	54	.51	.56	.53	.51	55	52	.50	53	51	.49	52	.50	48	.47	
	4	.53	.49	.46	52	.49	.46	51	.48	.45	49	.47	45	48	47	.44	.43	
	5	.49	.46	.42	.48	.46	.42	47	.44	.42	46	43	.41	45	.43	.41	.40	
	6	.45	.42	.39	.45	.41	39	44	41	.38	43	40	.38	.42	40	.38	.37	
	7	42	.38	.36	.42	.38	.35	41	.38	.35	40	37	.35	40	37	.35	.34	
	8	39	35	.33	.39	.35	.32	38	35	.32	37	34	.32	37	.34	.32	.31	Medium distribution reflector and concave lens
	9	36	.32	.30	.36	.32	.30	35	.32	29	35	32	.29	34	31	.29	28	
Max. S/MH_{wp} = 1.3	10	32	.28	25	32	.28	25	31	28	25	31	27	.25	30	.27	25	.24	LDD Maint. Category V
12	1	75	.73	.71	.73	.71	.70	70	.69	.68	68	.67	.66	66	65	64	.63	
	2	68	.65	.62	67	.64	.62	65	62	60	63	61	59	.61	59	.58	.57	
	3	63	59	.55	62	.58	.54	.60	57	.53	58	.56	.52	57	.55	.52	.51	
	4	58	.53	50	57	.53	50	55	52	49	54	.51	.48	53	.50	48	.47	
	5	.53	.48	.45	52	.48	.45	51	47	.44	50	.46	.44	.49	.46	.43	.42	
	6	.49	44	.41	.49	.44	.41	47	.43	.40	46	.43	.40	.45	.42	.40	.39	
	7	.45	.40	.37	.45	.40	.37	.44	40	37	.43	.39	.37	42	.39	36	.35	
	8	.42	.37	34	41	.37	.34	.40	.36	.33	40	.36	.33	39	.36	.33	.32	Wide distribution reflector and flat lens
	9	38	.33	.30	38	.33	.30	.37	.33	.30	36	32	.30	.36	.32	.30	.28	
Max. S/MH_{wp} = 1.2	10	.35	.30	.27	.35	.30	.27	.34	.30	.27	.34	.30	.27	.33	.29	.27	.26	LDD Maint. Category V

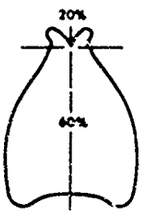
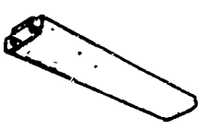
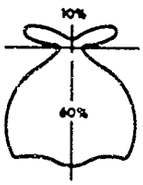
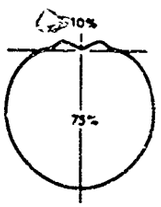
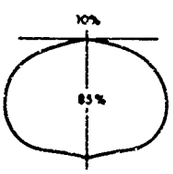
[a] Ratio of maximum spacing between luminaire centers to mounting (or ceiling) height above the work plane. See "Luminaire Spacing" on page 9-16.
[b] RCR = Room Cavity Ratio.
[c] ρ_{CC} = Per cent effective ceiling cavity reflectance.
[d] ρ_W = Per cent wall reflectance.
[e] See pages 9-16 and 9-17.

Fig. 9.4 (continued)

Typical Distribution and Maximum Spacing[a]	ρ_{cc}[c]	80			70			50			30			0			Typical Luminaires and Luminaire Maintenance Category[e]
	ρ_w[d]	50	30	10	50	30	10	50	30	10	50	30	10	50	30	10	0	
	RCR[b]	Coefficients of Utilization for 20 Per Cent Effective Floor Cavity Reflectance of																
13																		
0% / 45%	1	50	49	49	49	49	48	48	47	46	46	45	45	44	44	44	43	
	2	48	46	45	47	45	44	45	44	43	44	43	42	43	42	41	41	
	3	45	43	42	45	43	42	44	42	41	42	41	40	41	40	40	39	
	4	43	41	39	42	40	39	41	40	39	41	39	38	40	39	38	37	
	5	41	39	37	40	38	37	40	38	37	39	38	36	38	37	36	36	
	6	39	37	36	39	37	36	38	37	35	38	36	35	37	36	35	34	
	7	38	36	34	38	36	34	37	35	34	37	35	34	36	35	34	33	
	8	36	34	33	36	34	33	36	34	33	35	34	32	35	33	32	32	Reflector downlight with baffles—inside frosted lamp
	9	35	32	31	34	32	31	34	32	31	34	32	31	33	32	31	30	
Max. S/MH$_{wp}$ = 0.8	10	33	31	29	33	31	29	32	30	29	32	30	29	32	30	29	29	LDD Maint. Category IV
14																		
0% / 55%	1	62	61	60	60	60	59	58	58	57	56	56	56	55	54	54	53	
	2	58	57	56	58	56	55	56	55	54	54	53	53	53	52	51	51	
	3	56	54	53	55	54	52	54	53	51	53	52	51	52	51	50	49	
	4	53	51	50	53	51	49	52	50	49	51	49	48	50	49	48	47	
	5	51	49	47	51	49	47	50	48	47	49	47	46	48	47	46	45	
	6	50	47	46	49	47	46	49	47	45	48	46	45	47	46	45	44	
	7	48	46	44	48	46	44	47	45	44	47	45	44	46	45	44	43	
	8	46	44	43	46	44	42	46	44	42	45	43	42	45	43	42	41	PAR-38 flood with concentric louver
	9	45	42	41	44	42	41	44	42	40	43	42	40	43	41	40	40	
Max S/MH$_{wp}$ = 0.5	10	43	40	39	42	40	39	42	40	39	42	40	39	41	40	39	38	LDD Maint. Category IV
15																		
0% / 65%	1	74	72	71	72	71	70	70	69	68	67	67	66	65	65	64	63	
	2	69	67	65	68	66	65	66	65	63	64	63	62	63	62	61	60	
	3	66	63	61	65	63	61	64	61	60	62	60	59	61	59	58	57	
	4	63	60	58	62	59	57	60	58	57	59	58	56	58	57	55	55	
	5	60	57	54	59	56	54	58	56	54	57	55	53	56	54	53	52	
	6	57	54	52	57	54	52	56	54	52	55	53	51	55	53	51	50	
	7	55	52	50	55	52	50	54	51	50	53	51	49	53	51	49	48	
	8	53	50	48	52	50	48	52	49	47	51	49	47	51	49	47	46	
	9	50	47	45	50	47	45	49	47	45	49	47	45	48	46	45	44	R-40 flood with reflector skirt
Max. S/MH$_{wp}$ = 0.6	10	48	45	43	48	45	43	47	44	43	47	44	42	46	44	42	42	LDD Maint. Category IV
16																		
75% / 60%	1	84	80	77	79	76	74	71	69	67	64	62	60	57	55	54	51	
	2	73	68	64	70	65	61	63	59	56	56	53	51	50	48	46	43	
	3	65	59	53	62	58	51	56	51	47	50	46	44	45	42	40	37	
	4	58	51	45	55	49	44	50	45	41	45	41	37	40	37	34	32	
	5	51	44	38	48	42	37	44	39	35	40	35	32	36	32	30	27	
	6	46	38	33	44	37	32	39	34	30	36	31	28	32	28	26	24	
	7	41	34	29	39	33	28	36	30	26	32	28	25	29	26	23	21	
	8	37	30	25	35	28	24	32	26	23	29	24	21	26	22	20	18	Suspended semi-direct panel fluorescent lamp
	9	33	26	22	31	25	21	29	23	20	26	22	18	24	20	17	15	
Max. S/MH$_{wp}$ = 1.1	10	30	24	19	28	23	18	26	21	17	24	19	16	22	18	15	13	LDD Maint. Category III

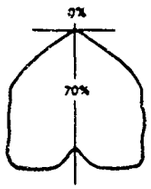
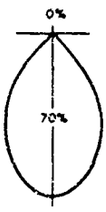
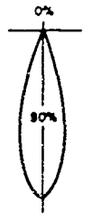
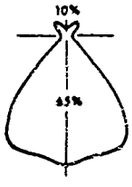
[a] Ratio of maximum spacing between luminaire centers to mounting (or ceiling) height above the work plane. See "Luminaire Spacing" on page 9-16.
[b] RCR = Room Cavity Ratio
[c] ρ_{CC} = Per cent effective ceiling cavity reflectance.
[d] ρ_w = Per cent wall reflectance
[e] See pages 9-16 and 9-17.

Fig. 9–4. Continued

Typical Distribution and Maximum Spacing[a]	ρ_{CC}[c] →	80			70			50			30			10			0	Typical Luminaires and Luminaire Maintenance Category[e]
	ρ_W[d] →	50	30	10	50	30	10	50	30	10	50	30	10	50	30	10	0	
	RCR[b] ↓	Coefficients of Utilization for 20 Per Cent Effective Floor Cavity Reflectance, ρ_{FC}																
17	1	.81	.78	.74	.77	.74	.71	.70	.67	.65	.63	.61	.60	.57	.56	.54	.51	
	2	.72	.67	.63	.69	.64	.60	.63	.59	.56	.56	.54	.52	.52	.50	.48	.45	
	3	.65	.59	.54	.62	.57	.52	.57	.53	.49	.52	.49	.46	.48	.45	.43	.40	
	4	.58	.52	.47	.56	.50	.46	.51	.47	.43	.47	.44	.40	.43	.41	.38	.36	
	5	.53	.47	.42	.51	.45	.41	.47	.42	.38	.43	.39	.36	.40	.37	.34	.32	
	6	.48	.42	.38	.47	.41	.36	.43	.38	.35	.40	.36	.33	.37	.34	.31	.29	
	7	.44	.38	.34	.43	.37	.33	.40	.35	.31	.37	.33	.30	.34	.31	.28	.26	
	8	.41	.34	.30	.39	.33	.29	.37	.32	.28	.34	.30	.27	.31	.28	.25	.24	
	9	.37	.31	.27	.36	.30	.27	.34	.29	.25	.31	.27	.24	.29	.26	.23	.22	Prismatic square surface drum
Max. S/MH_{wp} = 1.2	10	.33	.27	.23	.32	.27	.23	.30	.25	.22	.28	.24	.21	.26	.22	.20	.18	LDD Maint. Category V
18	1	.70	.68	.65	.67	.65	.63	.63	.61	.60	.59	.57	.56	.55	.54	.53	.51	
	2	.63	.59	.55	.61	.57	.54	.57	.54	.51	.52	.51	.49	.50	.48	.46	.44	
	3	.56	.51	.47	.54	.50	.46	.51	.47	.44	.48	.45	.42	.45	.43	.40	.39	
	4	.50	.45	.41	.49	.44	.40	.46	.42	.39	.43	.40	.37	.41	.39	.36	.34	
	5	.45	.40	.35	.44	.39	.35	.41	.37	.34	.39	.35	.32	.37	.34	.31	.30	
	6	.41	.35	.31	.39	.34	.30	.37	.33	.29	.35	.31	.29	.33	.30	.27	.26	2-lamp prismatic wrap-around. (Multiply by 1.0 for 4-lamp if unit is twice as wide)
	7	.36	.31	.27	.35	.30	.27	.34	.29		.32	.28	.25	.30	.27	.24	.23	
	8	.33	.27	.23	.32	.27	.23	.30	.26	.2[illegible]	.29	.25	.22	.27	.24	.21	.20	
	9	.29	.24	.20	.29	.23	.20	.27	.22	.19	.26	.22	.19	.24	.21	.18	.17	
Max. S/MH_{wp} = 1.6	10	.26	.21	.18	.26	.21	.18	.24	.20	.17	.23	.19	.16	.22	.18	.16	.15	LDD Maint. Category V
19	1	.83	.79	.75	.80	.76	.73	.75	.72	.69	.70	.67	.65	.65	.63	.61	.59	
	2	.71	.65	.59	.69	.63	.58	.64	.59	.55	.60	.56	.52	.56	.52	.49	.47	
	3	.62	.55	.49	.60	.53	.47	.56	.50	.45	.52	.47	.43	.49	.45	.41	.39	
	4	.55	.47	.40	.53	.45	.40	.49	.43	.38	.46	.41	.36	.43	.39	.35	.33	
	5	.48	.39	.33	.46	.38	.33	.43	.37	.32	.40	.35	.30	.38	.33	.29	.27	
	6	.42	.34	.29	.41	.33	.28	.38	.32	.27	.36	.30	.26	.34	.29	.25	.23	
	7	.38	.30	.25	.37	.29	.24	.35	.28	.23	.32	.27	.22	.30	.25	.22	.20	
	8	.34	.26	.21	.33	.26	.21	.31	.25	.20	.29	.23	.19	.27	.22	.19	.17	Surface-mounted bare lamp unit
	9	.30	.23	.18	.29	.22	.18	.28	.21	.17	.26	.20	.16	.25	.20	.16	.14	
Max. S/MH_{wp} = 1.5	10	.28	.20	.16	.27	.20	.16	.25	.19	.15	.24	.18	.15	.22	.18	.14	.12	LDD Maint. Category I
20	1	.91	.88	.85	.89	.86	.83	.85	.83	.81	.82	.80	.78	.79	.78	.76	.74	
	2	.80	.74	.70	.78	.73	.69	.75	.71	.67	.72	.69	.66	.70	.67	.64	.63	
	3	.70	.64	.58	.69	.63	.58	.67	.61	.57	.64	.60	.56	.62	.58	.55	.53	
	4	.62	.55	.49	.61	.54	.49	.59	.53	.48	.57	.52	.48	.55	.51	.47	.45	
	5	.54	.47	.41	.53	.46	.41	.51	.45	.40	.50	.44	.40	.48	.43	.39	.38	
	6	.48	.41	.35	.48	.40	.35	.46	.39	.35	.45	.39	.34	.43	.38	.34	.32	
	7	.43	.36	.30	.43	.35	.30	.41	.35	.30	.40	.34	.30	.39	.34	.29	.28	Porcelain-enameled ventilated standard dome with incandescent lamp
	8	.39	.31	.26	.38	.31	.26	.37	.30	.26	.36	.30	.25	.35	.29	.25	.24	
	9	.35	.27	.22	.34	.27	.22	.33	.27	.22	.32	.26	.22	.31	.26	.22	.20	
Max. S/MH_{wp} = 1.3	10	.31	.24	.19	.31	.24	.19	.30	.24	.19	.29	.23	.19	.28	.23	.19	.18	LDD Maint. Category III

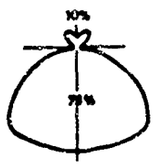
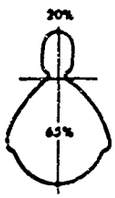
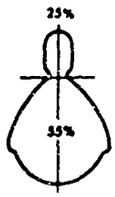
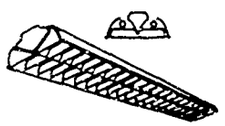
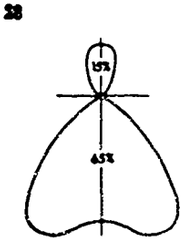
[a] Ratio of maximum spacing between luminaire centers to mounting (or ceiling) height above the work plane. See "Luminaire Spacing" on page 9-16.
[b] RCR = Room Cavity Ratio.
[c] ρ_{CC} = Per cent effective ceiling cavity reflectance.
[d] ρ_W = Per cent wall reflectance.
[e] See pages 9-16 and 9-17.

Fig. 9–4. *Continued*

Typical Distribution and Maximum Spacing[a]	ρ_{CC}[c] →	80			70			50			30			10			0	Typical Luminaires and Luminaire Maintenance Category[e]
	ρ_W[d] →	50	30	10	50	30	10	50	30	10	50	30	10	50	30	10	0	
	RCR[b] ↓	Coefficients of Utilization for 20 Per Cent Effective Floor Cavity Reflectance, ρ_{FC}																
21																		
	1	.78	.77	.74	.76	.75	.73	.74	.72	.71	.71	.70	.68	.68	.67	.66	.65	
	2	.72	.68	.66	.71	.67	.65	.68	.66	.63	.65	.64	.62	.64	.62	.61	.59	
	3	.66	.62	.59	.65	.61	.58	.63	.60	.57	.61	.59	.56	.60	.57	.55	.54	
	4	.60	.56	.52	.59	.55	.52	.58	.54	.51	.56	.53	.51	.55	.53	.50	.49	
	5	.55	.50	.47	.54	.50	.46	.53	.49	.46	.52	.48	.46	.51	.48	.45	.44	
	6	.51	.45	.42	.50	.45	.42	.49	.45	.41	.48	.44	.41	.47	.43	.41	.40	
	7	.46	.41	.37	.46	.41	.37	.45	.40	.37	.44	.40	.37	.43	.39	.36	.35	
	8	.42	.37	.33	.42	.37	.33	.41	.36	.33	.40	.36	.33	.39	.35	.33	.31	Enclosed reflector with incandescent lamp
Max. S/MH_{wp} = 1.5	9	.39	.33	.30	.38	.33	.30	.37	.33	.30	.37	.32	.29	.36	.32	.29	.28	LDD Maint. Category V
	10	.33	.28	.25	.33	.28	.25	.32	.28	.25	.32	.28	.24	.31	.27	.24	.23	
22																		
	1	.75	.73	.71	.74	.72	.70	.71	.69	.68	.68	.67	.66	.66	.65	.64	.62	
	2	.68	.64	.61	.67	.63	.61	.64	.62	.59	.62	.60	.58	.60	.58	.57	.55	
	3	.62	.57	.54	.60	.56	.53	.59	.55	.52	.57	.54	.51	.55	.53	.50	.49	
	4	.56	.52	.47	.55	.51	.47	.53	.49	.46	.52	.48	.45	.50	.47	.45	.44	
	5	.50	.45	.41	.49	.44	.41	.48	.44	.40	.47	.43	.40	.46	.42	.40	.38	
	6	.45	.40	.36	.45	.40	.36	.43	.39	.36	.42	.38	.65	.41	.38	.35	.34	Medium distribution, ventilated aluminum or glass reflector with improved-color mercury lamp
	7	.41	.36	.32	.40	.35	.32	.40	.35	.31	.39	.34	.31	.38	.34	.31	.30	
	8	.37	.32	.28	.37	.32	.28	.36	.31	.28	.35	.31	.28	.34	.30	.28	.26	
	9	.33	.28	.24	.33	.28	.24	.32	.28	.24	.32	.27	.24	.31	.27	.24	.23	
Max. S/MH_{wp} = 1.2	10	.30	.25	.22	.30	.25	.22	.29	.25	.22	.29	.25	.22	.28	.24	.21	.20	LDD Maint. Category III
23																		
	1	.89	.87	.85	.87	.85	.84	.84	.82	.81	.81	.80	.79	.78	.77	.77	.75	 
	2	.82	.79	.76	.81	.78	.76	.78	.76	.74	.76	.74	.72	.74	.72	.71	.69	
	3	.76	.72	.69	.75	.71	.69	.73	.70	.67	.71	.69	.66	.69	.67	.65	.64	
	4	.71	.66	.63	.70	.66	.62	.68	.65	.62	.67	.64	.61	.65	.62	.60	.59	
	5	.66	.61	.57	.65	.60	.57	.63	.59	.56	.62	.59	.56	.61	.58	.55	.54	400W 1000W
	6	.61	.56	.53	.61	.56	.53	.60	.55	.52	.59	.55	.52	.57	.54	.52	.50	Narrow distribution, ventilated aluminum or glass reflector with clear mercury lamp
	7	.57	.52	.48	.56	.52	.48	.55	.51	.48	.54	.50	.48	.54	.50	.47	.46	
	8	.53	.48	.44	.52	.47	.44	.51	.47	.44	.51	.47	.44	.50	.46	.43	.42	
	9	.49	.43	.40	.48	.43	.40	.47	.43	.40	.47	.42	.40	.46	.42	.39	.38	
Max. S/MH_{wp} = 0.6	10	.45	.40	.37	.45	.40	.37	.44	.39	.36	.43	.39	.36	.43	.39	.36	.35	LDD Maint. Category III
24																		
	1	.81	.79	.77	.77	.76	.74	.73	.71	.70	.68	.67	.66	.63	.63	.62	.60	
	2	.74	.71	.68	.72	.69	.66	.67	.65	.63	.63	.62	.60	.60	.58	.57	.55	
	3	.68	.64	.61	.66	.63	.59	.63	.60	.57	.59	.57	.55	.56	.54	.52	.51	
	4	.63	.58	.54	.61	.57	.53	.58	.54	.51	.55	.52	.49	.52	.50	.48	.46	
	5	.57	.52	.49	.56	.51	.48	.53	.49	.47	.51	.47	.45	.48	.46	.43	.42	
	6	.53	.48	.44	.52	.47	.43	.49	.45	.42	.47	.43	.41	.45	.42	.40	.38	Wide distribution, ventilated aluminum or glass reflector with improved-color mercury lamp
	7	.48	.43	.40	.47	.42	.39	.45	.41	.38	.43	.40	.37	.41	.38	.36	.35	
	8	.44	.39	.36	.43	.38	.35	.41	.37	.34	.40	.36	.33	.38	.35	.32	.31	
	9	.41	.35	.32	.40	.35	.31	.38	.34	.31	.36	.33	.30	.35	.32	.29	.28	
Max. S/MH_{wp} = 1.4	10	.35	.30	.27	.35	.30	.26	.33	.29	.26	.32	.28	.25	.30	.27	.24	.23	LDD Maint. Category III

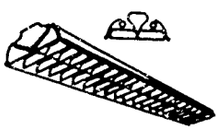
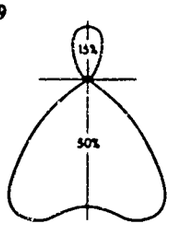
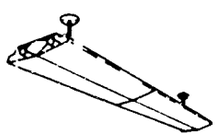
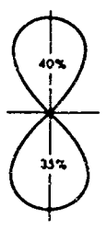
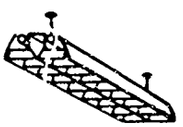
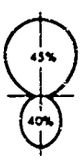
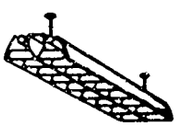
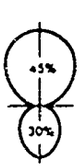
[a] Ratio of maximum spacing between luminaire centers to mounting (or ceiling) height above the work plane. See "Luminaire Spacing" on page 9-16.
[b] RCR = Room Cavity Ratio.
[c] ρ_{CC} = Per cent effective ceiling cavity reflectance.
[d] ρ_W = Per cent wall reflectance.
[e] See pages 9-16 and 9-17.

Fig. 9–4. *Continued*

Typical Distribution and Maximum Spacing[a]	ρ_{CC}[c] →	80			70			50			30			10			0	Typical Luminaires and Luminaire Maintenance Category[e]
	ρ_W[d] →	50	30	10	50	30	10	50	30	10	50	30	10	50	30	10	0	
	RCR[b] ↓	Coefficients of Utilization for 20 Per Cent Effective Floor Cavity Reflectance, ρ_{FC}																
25																		
	1	.87	.84	.81	.84	.81	.78	.79	.76	.74	.74	.72	.70	.69	.68	.66	.64	
	2	.76	.71	.66	.74	.69	.65	.69	.65	.62	.65	.62	.59	.61	.58	.56	.54	
	3	.67	.61	.56	.65	.59	.55	.61	.56	.52	.58	.54	.50	.54	.51	.48	.46	
	4	.60	.52	.47	.58	.51	.46	.55	.49	.44	.51	.47	.43	.48	.45	.41	.39	
	5	.52	.45	.39	.51	.44	.39	.48	.42	.38	.45	.40	.36	.43	.38	.35	.33	
	6	.47	.39	.34	.45	.38	.33	.43	.37	.32	.40	.35	.31	.38	.34	.30	.28	
	7	.42	.34	.29	.40	.33	.29	.38	.32	.28	.36	.31	.27	.34	.30	.26	.24	2-lamp porcelain-enameled industrial with 13° crosswise shielding
	8	.37	.30	.25	.36	.29	.25	.34	.28	.24	.32	.27	.23	.31	.26	.22	.21	
	9	.33	.26	.21	.32	.26	.21	.31	.25	.20	.29	.24	.20	.28	.23	.19	.18	
Max. S/MH$_{wp}$ = 1.3	10	.30	.23	.19	.29	.23	.18	.28	.22	.18	.26	.21	.17	.25	.20	.17	.15	LDD Maint. Category III
26																		
	1	.86	.83	.80	.82	.79	.77	.75	.72	.70	.68	.66	.65	.62	.61	.60	.57	
	2	.76	.71	.67	.73	.68	.65	.67	.63	.60	.61	.58	.56	.56	.54	.52	.49	
	3	.68	.62	.57	.65	.60	.56	.60	.56	.52	.55	.52	.49	.50	.48	.46	.43	
	4	.61	.54	.49	.58	.52	.48	.54	.49	.45	.49	.46	.42	.46	.42	.40	.38	
	5	.54	.47	.42	.52	.46	.41	.48	.43	.39	.44	.40	.37	.41	.37	.35	.33	
	6	.49	.42	.37	.47	.40	.36	.43	.38	.34	.40	.36	.32	.37	.33	.30	.29	
	7	.44	.37	.32	.42	.36	.31	.39	.34	.30	.36	.32	.28	.34	.30	.27	.25	2-lamp porcelain-enameled industrial with 35° crosswise shielding
	8	.39	.32	.28	.38	.31	.27	.35	.30	.26	.32	.28	.25	.30	.26	.23	.22	
	9	.35	.29	.24	.34	.28	.23	.31	.26	.22	.29	.25	.21	.27	.23	.20	.18	
Max. S/MH$_{wp}$ = 1.3	10	.32	.26	.21	.31	.25	.21	.29	.23	.20	.27	.22	.19	.25	.21	.18	.16	LDD Maint. Category II
27																		
	1	.75	.72	.71	.71	.69	.68	.65	.64	.62	.59	.58	.57	.54	.53	.52	.50	
	2	.67	.64	.61	.64	.61	.59	.59	.56	.54	.54	.52	.50	.49	.47	.46	.44	
	3	.61	.56	.53	.58	.54	.51	.53	.50	.48	.49	.46	.44	.44	.42	.41	.39	
	4	.55	.50	.46	.53	.48	.45	.48	.45	.42	.44	.41	.39	.40	.38	.36	.34	
	5	.50	.44	.40	.48	.43	.39	.44	.40	.37	.40	.37	.34	.37	.34	.32	.30	
	6	.45	.39	.36	.43	.38	.35	.40	.36	.32	.36	.33	.30	.33	.30	.28	.27	
	7	.41	.35	.31	.39	.34	.30	.36	.32	.29	.33	.29	.27	.30	.27	.25	.24	2-lamp porcelain-enameled industrial with 35° crosswise and lengthwise shielding
	8	.37	.31	.27	.36	.30	.27	.33	.28	.25	.30	.26	.24	.27	.24	.22	.21	
	9	.33	.28	.24	.32	.27	.23	.30	.25	.22	.27	.23	.21	.25	.22	.19	.18	
Max. S/MH$_{wp}$ = 1.3	10	.30	.25	.21	.29	.24	.21	.27	.23	.20	.25	.21	.18	.23	.20	.17	.16	LDD Maint. Category II
28																		
	1	.84	.83	.79	.80	.78	.76	.74	.73	.71	.69	.68	.66	.64	.63	.62	.60	
	2	.75	.71	.68	.72	.69	.66	.67	.65	.62	.63	.60	.59	.58	.57	.55	.53	
	3	.68	.62	.58	.65	.61	.57	.61	.57	.54	.57	.54	.51	.53	.51	.49	.47	
	4	.61	.55	.51	.59	.54	.50	.55	.51	.47	.51	.48	.45	.48	.45	.43	.41	
	5	.55	.48	.44	.53	.47	.43	.50	.45	.41	.46	.43	.40	.44	.40	.38	.36	
	6	.49	.43	.38	.47	.42	.38	.45	.40	.36	.42	.38	.35	.39	.36	.33	.32	
	7	.44	.38	.34	.43	.37	.33	.40	.35	.32	.38	.34	.30	.36	.32	.29	.28	
	8	.39	.33	.29	.38	.32	.28	.36	.31	.27	.34	.30	.26	.32	.28	.25	.24	2-lamp aluminum industrial with 35° crosswise shielding
	9	.35	.30	.25	.34	.29	.25	.32	.27	.24	.30	.26	.23	.29	.25	.22	.21	
Max. S/MH$_{wp}$ = 1.5	10	.32	.26	.22	.31	.25	.22	.29	.24	.21	.28	.23	.20	.26	.22	.19	.18	LDD Maint. Category II

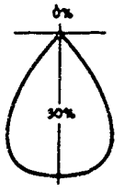
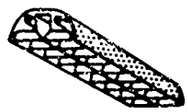
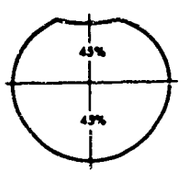
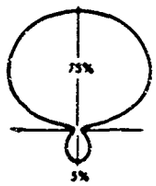
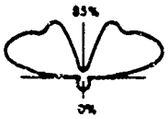
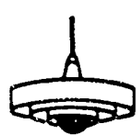
[a] Ratio of maximum spacing between luminaire centers to mounting (or ceiling) height above the work plane. See "Luminaire Spacing" on page 9-16.
[b] RCR = Room Cavity Ratio.
[c] ρ_{CC} = Per cent effective ceiling cavity reflectance.
[d] ρ_W = Per cent wall reflectance.
[e] See pages 9-16 and 9-17.

Fig. 9–4. *Continued*

Typical Distribution and Maximum Spacing[a]	ρ_{CC}[c] →	80			70			50			30			10			0	Typical Luminaires and Luminaire Maintenance Category[e]
	ρ_w[d] →	50	30	10	50	30	10	50	30	10	50	30	10	50	30	10	0	
	RCR[b] ↓	Coefficients of Utilization for 20 Per Cent Effective Floor Cavity Reflectance, ρ_{FC}																
29	1	66	64	62	64	62	60	58	57	55	53	52	51	49	48	47	45	
	2	60	56	54	57	54	52	53	50	48	49	47	45	45	43	42	40	
	3	54	50	46	52	48	45	48	45	42	44	42	40	41	39	37	36	
	4	49	44	41	47	43	40	44	40	38	40	38	35	38	35	34	32	
	5	44	39	35	42	38	35	39	36	33	37	34	31	34	32	30	28	
	6	40	35	31	38	34	31	36	32	29	33	30	28	31	29	27	25	
	7	36	31	28	35	30	27	33	29	26	30	27	25	28	26	24	22	2-lamp aluminum industrial with 35° crosswise and lengthwise shielding
	8	33	28	24	31	27	24	29	26	23	28	24	22	26	23	21	20	
	9	29	25	21	28	24	21	27	23	20	25	21	19	23	20	18	17	
Max. $S/MH_{wp} = 1.5$	10	27	22	19	26	21	18	24	20	18	23	19	17	21	18	16	15	LDD Maint. Category II
30	1	.70	.68	.65	65	63	.61	55	.53	.52	.45	.45	.44	.37	.36	.36	.32	
	2	62	.58	55	.58	.54	.51	49	.47	44	41	.39	.38	.34	.33	.32	.28	
	3	56	50	.47	52	.47	44	.44	.41	.38	37	.35	.33	30	29	.28	.25	
	4	49	.44	.40	46	.41	38	40	.36	.33	33	.31	.29	.28	.26	.25	.22	
	5	44	.39	.35	.41	.36	33	.36	32	29	30	.27	.25	.25	.23	.22	.20	
	6	40	.34	.30	.37	.32	.29	32	.28	.25	27	.24	.22	.23	.21	.19	.17	
	7	.36	30	.26	.34	.28	.25	29	.25	.22	25	.22	.19	.21	19	.17	.15	
	8	.33	.27	.23	30	.25	.22	26	22	20	22	20	.17	.19	.16	.15	.13	2-lamp prismatic lens bottom unit with open top
	9	29	.24	.20	27	.22	.19	24	20	.17	20	.17	.15	17	.15	.13	.11	
Max. $S/MH_{wp} = 1.2$	10	.27	21	.18	25	.20	.17	22	18	15	19	.15	.13	.16	.13	.12	.11	LDD Maint. Category VI
31	1	.79	.76	.73	73	70	.68	62	60	58	51	50	.49	.42	.41	.40	.36	
	2	.70	.65	.61	.65	61	.57	55	52	50	46	.44	.42	.38	.36	.35	.32	
	3	62	.56	.52	58	.53	.49	49	46	43	41	39	.36	.34	.33	.31	.28	
	4	.55	.49	.44	51	.46	.42	44	40	37	37	34	.32	31	.29	.27	.24	
	5	.49	43	.38	46	.40	36	40	35	32	34	30	27	28	.25	24	.21	
	6	.44	.38	.33	41	.35	.31	36	31	28	30	.27	.24	25	.23	.21	.19	
	7	40	.34	.29	37	.31	.27	32	28	24	27	24	.21	23	20	.19	.18	Direct-indirect with metal or dense diffusing sides and 35° x 45° louver shielding
	8	35	.29	.25	.33	.27	.24	29	24	.21	24	21	18	.20	.18	.16	.14	
	9	32	.25	.21	.30	.24	20	26	21	18	22	19	16	19	.16	.14	12	
Max. $S/MH_{wp} = 1.3$	10	30	.23	.19	28	22	.19	24	20	.16	20	17	14	17	.14	.12	.12	LDD Maint. Category II
32	1	70	.67	.65	64	.61	60	52	51	50	42	41	.40	32	32	.31	.27	
	2	62	.58	54	.57	53	.50	47	45	42	38	.36	35	29	29	.28	.24	
	3	55	.50	.46	50	46	.43	42	39	37	34	32	.30	27	26	25	21	
	4	.49	44	40	45	40	37	38	35	32	31	29	.27	25	.23	.22	.19	
	5	44	.38	.34	40	36	.32	34	30	28	28	25	24	.22	20	19	17	
	6	40	.34	.30	.37	.32	.28	.31	27	25	25	23	.21	.20	.19	.17	.15	
	7	.36	30	.26	33	.28	25	.28	24	22	23	20	.18	.19	.17	.15	.14	Direct-indirect with metal or dense diffusing sides and 45° louver shielding
	8	32	.27	.23	30	.25	.22	26	.22	19	21	19	.17	17	.15	.14	.12	
	9	.29	.24	.20	.27	.22	.19	.23	19	17	19	.16	.15	.16	.14	.12	.11	
Max. $S/MH_{wp} = 1.5$	10	.27	.22	.18	25	.20	.17	21	18	15	18	15	.13	.14	.12	.11	.10	LDD Maint. Category II

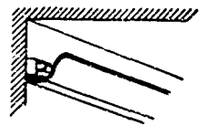
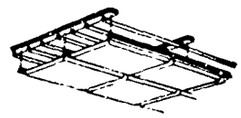
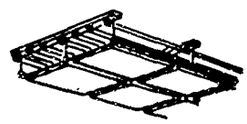
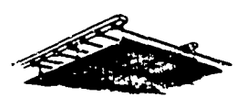
[a] Ratio of maximum spacing between luminaire centers to mounting (or ceiling) height above the work plane. See "Luminaire Spacing" on page 9-16.
[b] RCR = Room Cavity Ratio.
[c] ρ_{CC} = Per cent effective ceiling cavity reflectance
[d] ρ_w = Per cent wall reflectance.
[e] See pages 9-16 and 9-17

Fig. 9–4. *Continued*

Typical Distribution and Maximum Spacing[a]	ρ_{CC}[c] →	80			70			50			30			10			0	Typical Luminaires and Luminaire Maintenance Category[e]
	ρ_W[d] →	50	30	10	50	30	10	50	30	10	50	30	10	50	30	10	0	
	RCR[b] ↓	Coefficients of Utilization for 20 Per Cent Effective Floor Cavity Reflectance, ρ_{FC}																
33																		
	1	.54	.52	.51	.53	.51	.50	.51	.50	.48	.49	.48	.47	.47	.46	.46	.47	
	2	.49	.46	.44	.48	.45	.43	.46	.44	.42	.45	.43	.41	.43	.42	.40	.40	
	3	.44	.41	.38	.43	.40	.38	.42	.39	.37	.41	.39	.37	.39	.38	.36	.35	
	4	.40	.37	.34	.39	.36	.34	.38	.35	.33	.37	.35	.33	.36	.34	.32	.31	
	5	.36	.32	.30	.36	.32	.30	.35	.32	.29	.34	.31	.29	.33	.31	.29	.28	
	6	.33	.29	.27	.33	.29	.27	.32	.29	.26	.31	.28	.26	.30	.28	.26	.25	
	7	.30	.27	.24	.30	.26	.24	.29	.26	.24	.28	.26	.24	.28	.25	.23	.23	
	8	.28	.24	.21	.27	.24	.21	.27	.24	.21	.26	.23	.21	.26	.23	.21	.20	Unit #32 with top plates or surface-mounted
Max. $S/MH_{w_p} = 1.2$	10	.23	.20	.17	.23	.19	.17	.22	.19	.17	.22	.19	.17	.22	.19	.17	.18	LDD Maint. Category IV
34																		
	1	.79	.75	.70	.73	.69	.65	.61	.58	.55	.50	.47	.45	.40	.38	.36	.31	
	2	.67	.60	.55	.62	.56	.50	.51	.47	.42	.41	.38	.35	.32	.30	.28	.23	
	3	.58	.50	.44	.53	.46	.40	.44	.38	.34	.35	.31	.28	.28	.25	.22	.18	
	4	.50	.42	.36	.46	.39	.33	.38	.33	.28	.31	.27	.23	.24	.21	.18	.15	
	5	.44	.36	.30	.40	.33	.28	.34	.28	.23	.27	.22	.19	.21	.18	.15	.12	
	6	.39	.31	.25	.36	.29	.23	.30	.24	.20	.24	.19	.16	.19	.15	.12	.10	
	7	.35	.27	.21	.32	.25	.20	.27	.21	.17	.21	.17	.14	.17	.13	.10	.08	
	8	.31	.24	.18	.29	.22	.17	.24	.18	.14	.19	.15	.11	.15	.12	.09	.07	Incandescent pendant diffusing sphere
Max. $S/MH_{w_p} = 1.5$	10	.28	.21	.16	.26	.19	.15	.21	.16	.12	.17	.13	.10	.13	.10	.07	.06	LDD Maint. Category V
		.25	.18	.14	.23	.17	.13	.19	.14	.10	.16	.11	.08	.12	.09	.06	.05	
35																		
	1	.68	.65	.62	.59	.56	.54	.42	.41	.39	.26	.26	.26	.12	.12	.12	.06	
	2	.59	.54	.51	.51	.48	.44	.37	.35	.32	.23	.22	.21	.11	.11	.10	.05	
	3	.52	.46	.42	.45	.40	.37	.32	.29	.27	.20	.19	.18	.10	.09	.09	.04	
	4	.46	.40	.35	.40	.35	.31	.28	.25	.23	.18	.16	.15	.09	.08	.07	.04	
	5	.40	.34	.30	.35	.30	.26	.25	.22	.20	.16	.14	.13	.08	.07	.06	.03	
	6	.36	.30	.26	.31	.27	.23	.22	.20	.17	.15	.13	.11	.07	.06	.06	.03	
	7	.32	.26	.22	.28	.23	.19	.20	.17	.14	.13	.11	.09	.06	.05	.05	.03	
	8	.29	.23	.19	.25	.20	.17	.18	.15	.13	.12	.10	.08	.06	.05	.04	.02	Luminous direct unit for extra-high-output lamps
Max. $S/CH_{w_p} = 1.5$	10	.26	.20	.17	.23	.18	.15	.17	.13	.11	.10	.09	.07	.05	.04	.04	.02	LDD Maint. Category II
		.24	.18	.15	.21	.16	.13	.15	.12	.10	.10	.08	.06	.05	.04	.03	.02	
36																		
	1	.72	.69	.66	.62	.59	.57	.42	.41	.40	.25	.24	.24	.09	.09	.08	.01	
	2	.63	.58	.54	.54	.50	.47	.37	.35	.33	.22	.21	.20	.08	.07	.07	.01	
	3	.55	.49	.45	.47	.42	.39	.33	.30	.27	.19	.18	.16	.07	.06	.06	.01	
	4	.48	.42	.37	.42	.37	.33	.29	.26	.23	.17	.16	.14	.06	.06	.05	.01	
	5	.43	.36	.32	.37	.32	.28	.26	.22	.20	.15	.14	.12	.06	.05	.05	.01	
	6	.38	.32	.27	.33	.28	.24	.23	.19	.17	.14	.12	.10	.05	.04	.04	.01	
	7	.34	.28	.23	.29	.24	.20	.20	.17	.15	.12	.10	.09	.04	.04	.03	.01	
	8	.30	.24	.20	.26	.21	.18	.18	.15	.13	.11	.09	.08	.04	.03	.03	.00	Concentric ring, silvered-bowl indirect
	9	.28	.22	.18	.24	.19	.15	.17	.13	.11	.10	.08	.07	.04	.03	.02	.00	
Max. $S/CH_{w_p} = 1.5$	10	.25	.19	.15	.21	.17	.13	.15	.12	.09	.09	.07	.06	.03	.02	.02	.00	LDD Maint. Category II

[a] Ratio of maximum spacing between luminaire centers to mounting (or ceiling) height above the work plane. See "Luminaire Spacing" on page 9-16.
[b] RCR = Room Cavity Ratio.
[c] ρ_{CC} = Per cent effective ceiling cavity reflectance.
[d] ρ_W = Per cent wall reflectance.
[e] See pages 9-16 and 9-17

Fig. 9–4. *Continued*

Typical Distribution and Maximum Spacing[a]	ρ_{CC}[c] →	80			70			50			30			10			0	Typical Luminaires and Luminaire Maintenance Category[e]
	ρ_w[d] →	50	30	10	50	30	10	50	30	10	50	30	10	50	30	10	0	
	RCR[b] ↓	Coefficients of Utilization for 20 Per Cent Effective Floor Cavity Reflectance, ρ_{FC}																
37																		
	1	.42	.40	.39	.36	.35	.33	.25	.24	.23	Coves are not recommended for lighting areas having low reflectances.							
	2	.37	.34	.32	32	.29	.27	.22	.20	.19								
	3	.32	.29	.26	.28	.25	.23	.19	.17	.16								Fluorescent cove without reflector. These values apply to coves employing a single row of fluorescent lamps. If two rows are used multiply CU's by 0.93. For three rows multiply by 0.85.
	4	.29	.25	.22	.25	.22	.19	.17	.15	.13								
	5	.25	.21	.18	.22	19	.16	.15	.13	.11								
	6	.23	.19	.16	.20	.16	.14	.14	.12	.10								
	7	.20	.17	.14	.17	.14	.12	.12	.10	09								
	8	.18	.15	.12	.16	.13	.10	.11	.09	.08								
See discussion of coves on page 9-21.	9	.17	.13	.10	.15	.11	.09	.10	.08	.07								
	10	.15	.12	.09	.13	.10	.08	.09	.07	.06								LDD Maint. Category VI
38																		
	1				.60	.58	.56	58	.56	.54								
	2				.53	.49	.45	.51	.47	.43								
	3				47	.42	.37	.45	.41	.36								
	4				.41	.36	.32	.39	.35	.31								
	5				.37	.31	.27	35	.30	.26								
	6				.33	.27	.23	.31	.26	.23								
	7				.29	24	.20	28	23	.20								
See discussion of diffusing ceilings on page 9-18.	8				.26	.21	.18	.25	20	.17								Diffusing plastic or glass extended area system
	9				.23	19	.15	23	.18	.15								
	10				.21	.17	.13	21	.16	.13								LDD Maint. Category VI
39																		
	1				71	.68	.66	67	.66	.65	65	.64	.62					
	2				.63	.60	.57	.61	.58	.55	.59	.56	.54					
	3				.57	.53	.49	.55	.52	.48	54	.50	.47					
	4				.52	.47	.43	.50	.45	.42	48	.44	.42					
	5				.46	.41	.37	.44	.40	.37	.43	.40	.36					
	6				.42	.37	.33	.41	36	.32	.40	.35	.32					
	7				.38	.32	29	.37	.31	.28	36	.31	.28					
See discussion of prismatic ceilings on page 9-18.	8				.34	.28	.25	33	28	.25	32	.28	.25					Prismatic plastic or glass extended area system
	9				.30	.25	.22	30	.25	.21	29	.25	.21					
	10				.27	.23	.19	27	.22	.19	26	.22	.19					LDD Maint. Category VI
40																		
	1							.51	.49	.48				.47	.46	.45		
	2							.46	.44	.42				.43	.42	.40		
	3							.42	.39	.37				.39	.38	.36		
	4							.38	.35	.33				.36	.34	.32		
	5							.35	.32	.29				.33	.31	.29		
	6							.32	.29	.26				.30	.28	.26		
	7							.29	.26	.23				.28	.25	.23		
See discussion of louvered ceilings on page 9-20.	8							.27	.23	.21				.26	.23	.21		Louvered extended area system
	9							.24	.21	.19				.24	.21	.19		
	10							.22	.19	.17				.22	.19	.17		LDD Maint. Category II

[a] Ratio of maximum spacing between luminaire centers to mounting (or ceiling) height above the work plane. See "Luminaire Spacing" on page 9-16.
[b] RCR = Room Cavity Ratio.
[c] ρ_{CC} = Per cent effective ceiling cavity reflectance.
[d] ρ_w = Per cent wall reflectance.
[e] See pages 9-16 and 9-17.

Fig. 9–5. Factors for Effective Floor Cavity Reflectances Other Than 20 Per Cent

For 30 per cent effective floor cavity reflectance, multiply by appropriate factor below.
For 10 per cent effective floor cavity reflectance, divide by appropriate factor below.

Per Cent Effective Ceiling Cavity Reflectance, ρ_{cc}	80			70			50			10		
Per Cent Wall Reflectance, ρ_w	50	30	10	50	30	10	50	30	10	50	30	10
Room Cavity Ratio												
1	1.08	1.08	1.07	1.07	1.06	1.06	1.05	1.04	1.04	1.01	1.01	1.01
2	1.07	1.06	1.05	1.06	1.05	1.04	1.04	1.03	1.03	1.01	1.01	1.01
3	1.06	1.04	1.03	1.05	1.04	1.03	1.03	1.03	1.02	1.01	1.01	1.01
4	1.05	1.03	1.02	1.04	1.03	1.02	1.03	1.02	1.02	1.01	1.01	1.00
5	1.04	1.03	1.02	1.03	1.02	1.02	1.02	1.02	1.01	1.01	1.01	1.00
6	1.03	1.02	1.01	1.03	1.02	1.01	1.02	1.02	1.01	1.01	1.01	1.00
7	1.03	1.02	1.01	1.03	1.02	1.01	1.02	1.01	1.01	1.01	1.01	1.00
8	1.03	1.02	1.01	1.02	1.02	1.01	1.02	1.01	1.01	1.01	1.01	1.00
9	1.02	1.01	1.01	1.02	1.01	1.01	1.02	1.01	1.01	1.01	1.01	1.00
10	1.02	1.01	1.01	1.02	1.01	1.01	1.02	1.01	1.01	1.01	1.01	1.00

Fig. 9–6. Lamp Lumen Depreciation (LLD)
(Per cent of initial lumens produced at
70 per cent of life*)

Lamp Description		LLD Factor		
Incandescent				
General service	to 150 W	91		
	250 to 500 W	90		
	750 to 1500 W	86		
Silver-bowl	200 to 500 W	75		
Reflector	R40	86		
	R52 and R57	81		
Projector	PAR 38 to 64	84		
Mercury				
H39-22 KB	175 W	85		
H39-22 KC/C	175 W	83		
H39-22 KC/W	175 W	75		
H37-5 KB	250 W			
H37-5 KC/C	250 W	83		
H37-5 KC/W	250 W	73		
H33-1 CD	400 W	86		
H33-1 GL/C	400 W	83		
H33-1 GL/W	400 W	74		
H36-15 GV	1000 W	77		
H36-15 GW/C	1000 W	72		
H36-15 GW/W	1000 W	61		
Fluorescent		Hours per Start		
		6	12	18
Instant start 425 ma				
Standard colors**		88	87	85
Improved-color types***		82	80	78
Rapid start 430 ma				
Standard colors**		87	86	85
Improved-color types***		81	80	79
Rapid start 800 ma				
Standard colors**		81	79	77
Rapid start 1500 ma				
Tubular**		76	74	72
Others**		70	68	64

* Factors shown are averages for groups of lamps at design conditions and should be compensated to reflect operations in the field. Improvements in lamp design are being made so rapidly that it is important, for accuracy, to consult the manufacturer's up-to-date statistics for the particular lamp considered.

** Cool white, warm white, white, daylight.

*** Deluxe cool white and deluxe warm white.

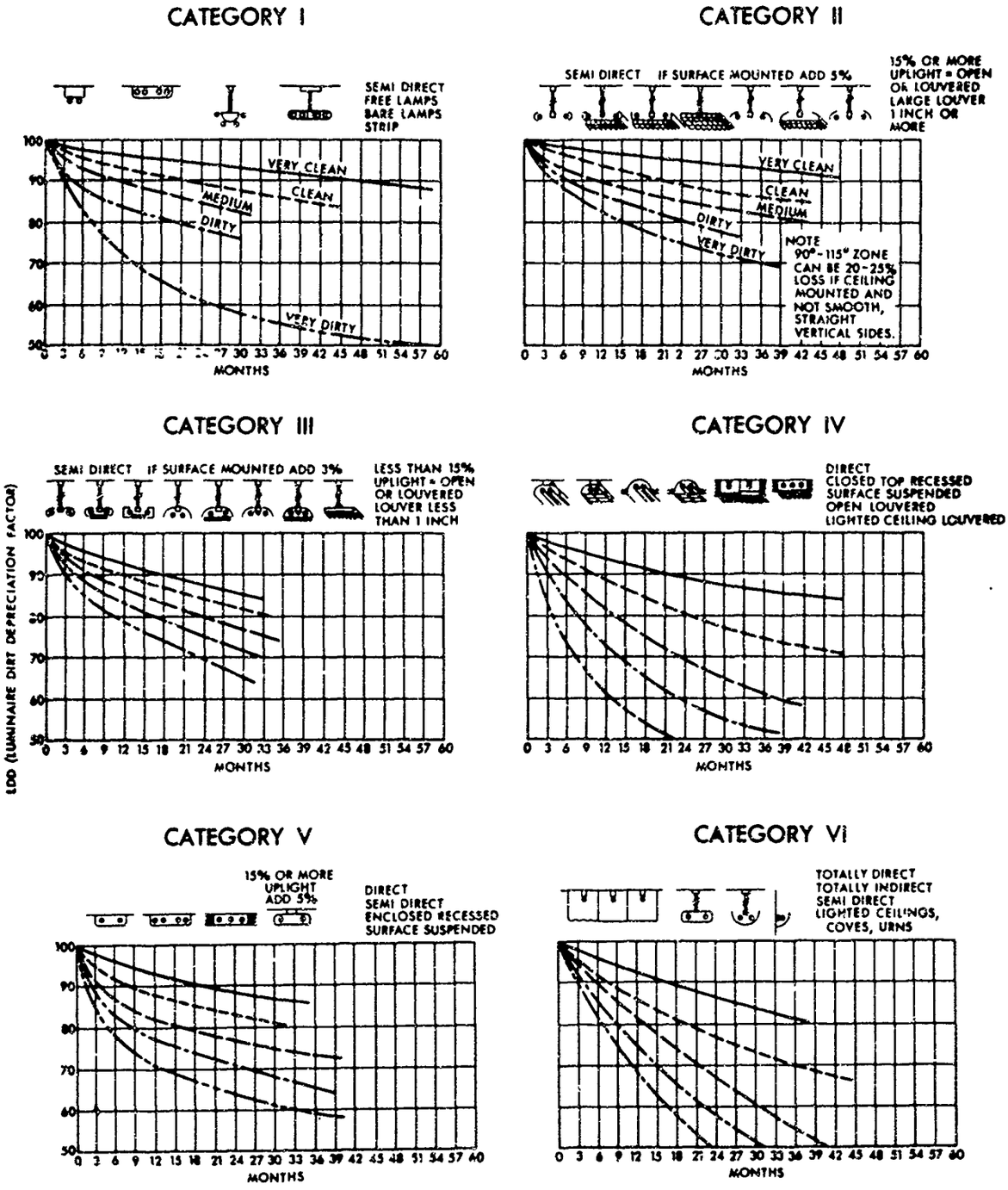


Fig. 9–7. Luminaire Dirt Depreciation factors (LDD) for six luminaire categories (I to VI) and for five degrees of dirtiness as determined from either Figs. 9–8 or 9–9.

Fig. 9–b. Five Degrees of Dirt Conditions

	Very Clean	Clean	Medium	Dirty	Very Dirty
Generated Dirt	None	Very little	Noticeable but not heavy	Accumulates rapidly	Constant accumulation
Ambient Dirt	None (or none enters area)	Some (almost none enters)	Some enters area	Large amount enters area	Almost none excluded
Removal or Filtration	Excellent	Better than average	Poorer than average	Only fans or blowers if any	None
Adhesion	None	Slight	Enough to be visible after some months	High—probably due to oil, humidity, or static	High
Examples	High grade offices, not near production; laboratories; clean rooms	Offices in older buildings or near production; light assembly; inspection	Mill offices; paper processing; light machining	Heat treating; high speed printing; rubber processing	Similar to Dirty but luminaires within immediate area of contamination

Fig. 9–34. Wall and Ceiling Cavity Luminance Coefficients for Various Luminaire Distributions

Luminaire Type	Coefficient	ρ_{cc}[a] →	80			70			50			30			10		
		ρ_w[b] →	50	30	10	50	30	10	50	30	10	50	30	10	50	30	10
		RCR[c] ↓	Coefficients for 20 Per Cent Effective Floor Cavity Reflectance														
Distribution: 0% up, 100% down Efficiency: 50% Description: Two 40W, 1 x 4 recessed lens troffer	Wall	1	.12	.067	.021	.11	.065	.021	.11	.062	020	.010	.059	019	.096	056	.018
		2	.12	.063	.019	.11	062	019	11	.059	018	.010	.057	018	.098	055	.017
		3	.11	.058	.017	.11	057	.017	10	055	017	.097	053	016	093	.051	016
		4	.10	.054	.016	.10	.053	016	097	052	015	.093	.050	015	090	.049	.015
		5	.099	.050	.015	097	050	015	.093	049	014	088	.048	014	.087	046	.014
		6	.094	.047	.014	093	.047	013	.089	.046	013	086	045	.013	.083	044	013
		7	.089	.044	.012	.088	044	012	.085	.043	012	082	042	012	.079	.041	012
		8	.085	.042	012	084	041	012	081	041	012	079	040	.011	.078	039	011
		9	.082	.040	011	081	039	011	078	039	011	076	038	.011	074	.037	011
		10	.078	.037	010	077	037	010	075	037	010	.073	036	010	071	036	010
	Ceiling	1	.088	078	070	075	067	060	.051	.046	042	029	027	024	009	009	.008
		2	.082	066	053	070	057	046	048	.039	032	028	023	019	009	007	.006
		3	.077	.057	.041	.066	049	035	045	.034	025	026	020	.015	008	007	005
		4	.073	.050	032	063	043	028	043	030	020	025	018	012	008	006	004
		5	.070	045	026	.060	039	023	.041	.027	016	.024	016	009	008	005	003
		6	.067	040	021	.058	035	019	.040	.025	.015	.023	014	008	007	005	003
		7	064	037	018	.055	032	016	.038	022	011	.023	013	007	007	004	002
		8	.061	034	015	053	.030	013	.037	.021	.009	.021	012	006	007	004	.002
		9	059	032	.013	.051	.028	011	.035	.019	008	021	011	005	.007	004	.002
		10	057	030	011	049	028	010	.034	.018	007	.020	011	004	.007	004	.001

[a] Per cent effective ceiling cavity reflectance.
[b] Per cent wall reflectance.
[c] Room Cavity Ratio.

Fig. 9-34. *Continued*

Luminaire Type	Coefficient	ρ_{ceil}[a] →	80			70			50			30			10		
		ρ_{wall}[b] →	50	30	10	50	30	10	50	30	10	50	30	10	50	30	10
		RCR[c] ↓	Coefficients for 20 Per Cent Effective Floor Cavity Reflectance														
Distribution 90% up, 10% down Efficiency: 60% Description: Suspended indirect	Wall	1	15	086	027	13	075	024	092	053	017	058	034	011	025	015	005
		2	14	077	024	12	067	020	087	048	015	055	031	009	025	014	004
		3	13	069	021	11	060	018	080	043	013	051	028	009	023	013	004
		4	12	063	018	10	055	016	076	040	012	048	026	008	022	012	004
		5	11	058	017	099	051	015	071	037	011	045	024	007	021	011	003
		6	10	052	015	091	046	013	066	034	010	042	022	006	019	010	003
		7	099	049	014	086	043	012	062	031	009	040	020	006	019	010	003
		8	093	045	013	081	040	011	059	029	008	038	019	005	018	009	003
		9	087	042	012	076	037	010	055	027	008	036	018	005	017	009	003
		10	082	040	011	072	035	010	053	026	007	034	017	005	017	008	002
	Ceiling	1	52	50	49	44	43	43	30	30	29	17	17	17	055	055	055
		2	51	50	48	44	43	41	30	29	29	17	17	17	055	055	055
		3	51	49	47	44	42	40	30	29	28	17	17	17	055	055	054
		4	51	48	46	44	41	40	30	29	28	17	17	17	055	055	054
		5	50	48	46	43	41	39	30	29	28	17	17	17	055	054	054
		6	50	47	45	43	41	39	30	29	28	17	17	16	055	054	054
		7	50	47	45	43	41	39	30	28	28	17	17	16	055	054	054
		8	49	47	44	43	40	39	29	28	27	17	17	16	055	054	054
		9	49	46	44	42	40	39	29	28	27	17	17	16	055	054	054
		10	49	46	44	42	40	39	29	28	27	17	17	16	055	054	054
Distribution 30% up, 70% down Efficiency 70% Description Semi-direct with lens bottom	Wall	1	17	097	031	16	091	029	14	079	025	12	068	022	010	059	019
		2	16	089	027	15	084	026	13	075	023	12	065	020	010	057	018
		3	15	081	024	14	077	023	13	068	021	11	061	019	096	053	016
		4	14	075	022	14	071	021	12	064	019	11	057	017	093	050	015
		5	14	070	020	13	066	019	11	060	018	10	054	016	089	048	014
		6	13	086	018	12	062	018	11	055	016	097	050	015	085	045	013
		7	12	060	017	12	058	016	10	052	015	092	047	014	081	042	012
		8	12	057	016	11	054	015	099	049	014	088	045	013	078	040	012
		9	11	054	015	10	051	014	095	047	013	035	043	012	075	038	011
		10	10	050	014	10	048	013	090	044	012	081	040	011	073	037	010
	Ceiling	1	28	027	026	24	23	22	17	16	15	096	092	090	030	030	029
		2	28	025	024	24	22	20	16	15	13	094	088	083	030	028	027
		3	27	024	022	23	21	19	16	15	13	092	085	079	029	028	026
		4	27	023	021	23	20	18	16	14	13	091	082	076	029	027	025
		5	26	023	020	22	20	18	15	14	12	090	081	073	029	026	024
		6	26	022	020	22	19	17	15	13	12	089	079	071	029	026	023
		7	25	022	019	22	19	17	15	13	12	088	078	070	028	025	023
		8	025	021	019	21	18	16	15	13	12	087	077	069	028	025	023
		9	025	021	018	21	18	16	15	12	11	086	076	068	028	025	023
		10	024	021	018	21	18	16	15	13	11	085	075	068	028	025	022
Distribution: 50% up, 50% down Efficiency: 70% Description: Suspended general diffuse (direct-indirect)	Wall	1	17	098	031	16	089	028	13	073	023	10	058	019	077	04.	014
		2	16	089	027	15	082	025	12	068	021	099	056	018	077	044	014
		3	15	081	024	14	075	023	12	063	019	094	052	016	074	041	013
		4	14	074	022	13	069	020	11	058	017	089	048	014	070	038	012
		5	14	069	020	12	064	019	10	054	016	086	045	013	068	036	011
		6	13	084	018	12	059	017	098	050	015	081	042	012	065	034	010
		7	12	059	017	11	055	016	093	047	014	077	040	012	062	032	010
		8	11	055	016	10	051	015	088	044	013	074	037	011	.059	030	009
		9	10	052	015	10	049	014	085	042	012	071	35	010	057	029	008
		10	10	049	14	095	046	13	080	040	011	068	34	010	055	028	008

[a] Per cent effective ceiling cavity reflectance
[b] Per cent wall reflectance
[c] Room Cavity Ratio.

Fig. 9–34. *Continued*

Luminaire Type	Coefficient	ρ_{cc}[a] →	80			70			50			30			10		
		ρ_w[b] →	50	30	10	50	30	10	50	30	10	50	30	10	50	30	10
		RCR[c] ↓	Coefficients for 20 Per Cent Effective Floor Cavity Reflectance														
Distribution: 50% up, 50% down Efficiency: 70% Description: Suspended general diffuse (direct-indirect)	Ceiling	1	.39	.38	.37	.33	.32	.31	.23	.22	.22	.13	.13	.13	.042	.041	.041
		2	.38	.36	.34	.33	.31	.30	.23	.22	.21	.13	.13	.12	.041	.040	.039
		3	.38	.35	.33	.32	.30	28	.22	.21	.20	.13	.12	.12	.041	.040	.038
		4	.37	.34	.32	.32	.30	.28	.22	.21	.19	.13	.12	.11	041	039	.038
		5	.37	.34	.31	.32	.29	.27	.22	.20	.19	.13	.12	.11	.041	.039	.037
		6	.37	.33	.30	31	.29	27	.22	.20	.19	.13	.12	.11	.040	.038	.037
		7	.36	.33	30	.31	.28	.26	.22	.20	.19	12	.12	.11	.040	.038	.036
		8	.36	.33	.30	.31	.28	.26	21	20	.18	.12	11	.11	.040	.038	.036
		9	.36	.32	.30	.31	.28	26	.21	19	.18	.12	.11	.11	.040	.038	036
		10	.35	.32	.29	.30	.28	26	21	.19	.18	.12	.11	.11	.040	.037	.036
Distribution: 70% up, 30% down Efficiency: 70% Description: Suspended semi-indirect	Wall	1	.17	.099	.031	.16	.088	.028	12	.068	022	.085	.049	.016	.054	.031	.010
		2	.16	.090	.028	.15	.080	.025	11	.062	.020	.081	.046	.014	.053	.030	.009
		3	.15	.081	.024	.14	073	022	10	057	.017	.077	.042	.013	.051	.028	.009
		4	.14	.074	.022	.13	.067	.019	099	.053	.016	.073	.039	012	.048	.026	.008
		5	.13	.069	.020	.12	.062	.018	094	.049	.014	.069	.037	.011	047	.025	.008
		6	.13	.063	.018	.11	.057	016	088	.045	.013	.066	.034	.010	.044	.023	007
		7	.12	.058	.017	.10	.052	.015	083	.04.	.012	.062	.032	.009	.042	.022	006
		8	.11	.055	.015	.10	.049	.014	.079	.039	.011	.059	.030	.009	.040	.021	.006
		9	.10	.051	014	.095	.046	.013	075	037	.010	.057	.028	.008	.039	.020	.006
		10	.099	.048	.013	.080	.042	.012	.071	.035	.010	.054	.027	.008	.037	.019	.005
	Ceiling	1	.50	.49	.47	.43	.42	.41	29	29	.28	.17	.17	.16	.054	.053	.053
		2	.49	.47	.45	.42	41	.39	29	.28	.27	.17	.16	.16	.053	.052	052
		3	.49	.46	.44	.42	.40	.38	.29	.28	.27	.17	.16	16	.053	.052	051
		4	.48	.45	.43	.42	39	.37	.29	.27	.26	.17	16	.16	053	.052	.051
		5	.48	.45	.42	.41	.39	.37	28	27	26	.16	.16	.15	053	.051	.050
		6	.48	.44	.42	.41	.38	.36	.28	.27	.26	.16	.16	.15	.053	.051	.050
		7	.47	.44	.41	.41	.38	.36	28	.27	.26	.16	.16	.15	.052	.051	.050
		8	.47	.43	.41	.40	.38	.36	.28	26	.25	.16	.16	.15	.052	.050	050
		9	.47	.43	.41	.40	.37	.36	.28	.26	.25	.16	.16	.15	.052	.050	.049
		10	.46	.43	.40	.40	37	.35	.28	.26	.25	.16	.15	.15	.052	.050	.049

[a] Per cent effective ceiling cavity reflectance.
[b] Per cent wall reflectance.
[c] Room Cavity Ratio.

Both *maximum* and *average* luminances are significant factors in the control of direct glare, but

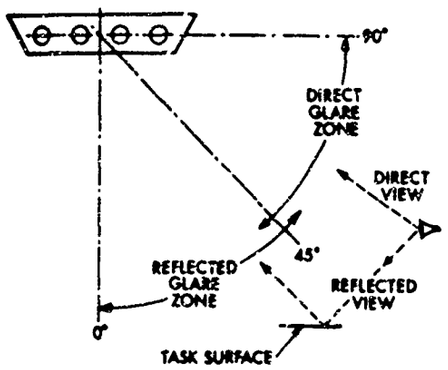


Fig. 11-2. The direct and reflected glare zones are generally defined as shown by the above diagram. Note that there is no sharp line of demarcation between these zones at 45 degrees.

average luminances are recognized as being the more pertinent. Luminaire luminance data and the ratios of maximum to average luminance should be provided for angles of 45, 55, 65, 75, and 85 degrees from nadir; and, in the case of luminaires with asymmetric distribution, they should be provided for both crosswise and lengthwise viewing.

Maximum luminance of luminaires should be the brightest square-inch at the specified angles as measured in the laboratory using IES-approved instruments and procedures (see Section 4).

Average luminances of luminaires are obtained by dividing the candlepower at each specified angle by the projected area (in square inches) of all luminaire elements contributing to that candlepower. The result (cd/in^2) may be converted to footlamberts by multiplying by 452 In computing average luminance, air space containing no light-generating or controlling elements should not be included as a part of the area. Opaque side panels may, however, be included as part of the projected area, if at least 15 per cent of the total output is in the 110 to 140-degree zone and if the side panel has high reflectance. Opaque end panels should not be included as projected area.

In determining the average luminance of luminaires to be mounted 6 inches or less from the top of the luminaire to the ceiling and which deliver 25 per cent or more of their output in the 90 to 180-degree zone when pendant mounted, candlepower data should be obtained with the luminaire mounted on a simulated ceiling board with a reflectance of 80 ± 3 per cent (see "IES Approved Method for Photometric Testing of Indoor Fluorescent Luminaires"*). The luminaire should be mounted on this board at the proposed mounting distance. The board should be included in the projected area as shown in Fig. 11-3.

Although luminance is only one of the factors that may cause direct glare, it is possible to use luminance as the only criterion by assuming a representative set of conditions that adequately recognize the other factors. Thus, in Fig. 11-4, the influence of the number of luminaires and their position in the field of view have been taken into account by assuming a specific room size and a typical installation of luminaires required to maintain a representative illumination level. It was further assumed that room surfaces had recommended reflectances to provide good environmental luminance relationships. The luminaire luminance limitations recommended in Fig. 11-4 are based on 30 to 100 footcandle installations in a 100 by 100-foot room having recommended ceiling and wall reflectances. The range in illumination levels is possible because the increase in adaptation level compensates for the larger number of luminaires required to provide the higher levels. Present knowledge does not permit extension of the recommendation beyond 100 footcandles, but it is obvious that luminaires having luminances that do not exceed the recommended values will be more suitable at all levels than those which have higher luminance.

Fig. 11-4 provides a means of determining the suitability of fluorescent luminaire average and maximum luminance distributions from the standpoint of preventing discomfort from direct glare for the conditions stated in the preceding paragraph. In small rooms where luminaire luminances at the

* To be published

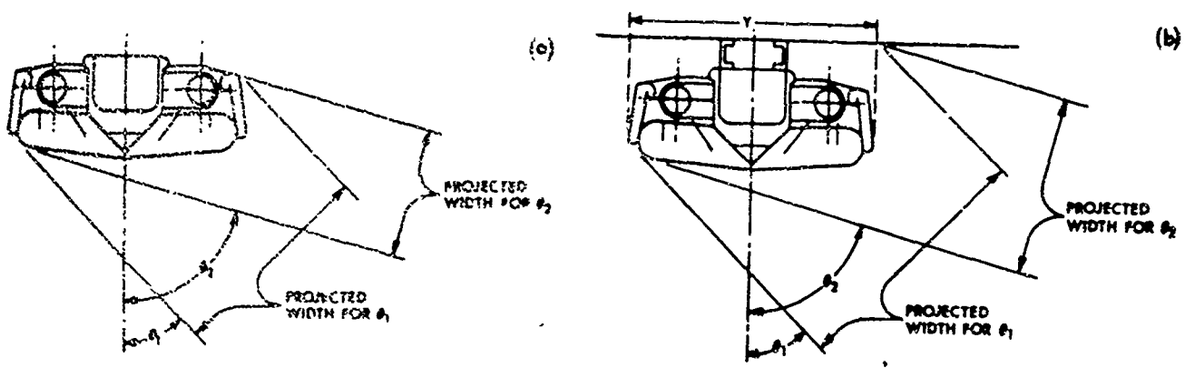


Fig. 11-3. Projected widths for use in calculating the projected area for average luminance calculations. (a) For all mounting except close to flat ceiling mounting. (b) For close to the ceiling mounting. Crosswise projected area is the length times the projected width. Endwise projected area is the width times the projected length or the width times the length times cos θ.

Fig. 11-4. IES Luminance Data Check Sheet
for Evaluating Luminaire Compliance with the "Scissors Curve" Criteria of
the American Standard Practice for Office Lighting[1] and the American Standard Guide for School Lighting[34].

Manufacturer's Company Name _____ Luminaire Catalog No. _____
Test Laboratory _____ Report No. _____
Lamp Description _____ No. of Lamps _____ Rated Lumens Each _____

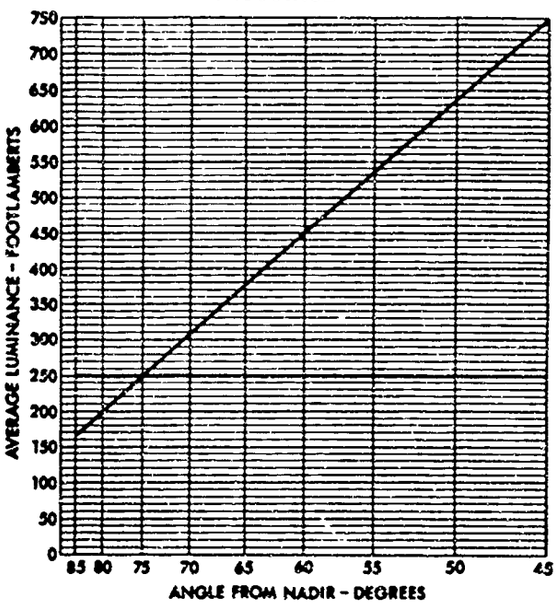
Direct glare should not be a problem in School and Office fluorescent lighting installations if ceiling and wall reflectances comply with recommendations in Table I below and if (1) luminaires have crosswise and lengthwise average luminance distributions which fall entirely below any straight line(s) drawn through 250 footlamberts at 75 degrees lying between the two limiting solid lines in Fig. 1 below, and (2) the ratio of maximum to average luminaire luminance preferably does not exceed 3 to 1, and definitely does not exceed 5 to 1 as shown in Table II below. The maximum luminance must never be more than three times the value of the sloped limiting line of the graph.

Table I—Recommended Surface Reflectances

OFFICES		SCHOOLS	
Ceiling	80 - 92%	Ceiling	70 - 90%
Walls	40 - 60%	Walls	40 - 60%
Furniture	26 - 44%	Chalkboards	up to 20%
Office Machines	26 - 44%	Desk	35 - 50%
Floor	21 - 39%	Floor	30 - 50%

Figure 1. Scissors Curve Graph

CROSSWISE



LENGTHWISE

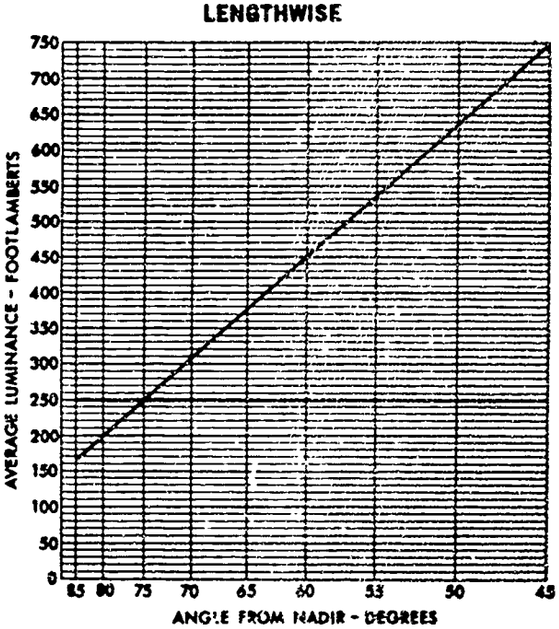


Table II—Maximum to Average Luminaire Luminance Ratios

CROSSWISE

Angle	3 Times Value*	Maximum	Average	Ratio Max/Avg
45°	2250			
55°	1605			
65°	1125			
75°	750			
85°	495			

LENGTHWISE

Angle	3 Times Value*	Maximum	Average	Ratio Max/Avg
45°	2250			
55°	1605			
65°	1125			
75°	750			
85°	495			

*Three times the value of the sloped limiting line, in footlamberts.
**If luminaire is to be lamped with lamps of a different lumen output than reported above, a new footlambert Data Check should be made using the proposed lamp's lumen rating. Also, if luminaire is to be mounted in a position other than reported above (*e.g.*, if unit has been photometered for suspension mounting over six inches, but is to be surface mounted), a new footlambert Data Check should be made using a test report for that mounting condition.

Luminaire as Lamped and Tested**	COMPLIES	
	DOES NOT COMPLY	

higher angles will not be within the field of view, the limitations at those angles may be disregarded. The highest significant angle should be determined by a cross-section sketch, with an occupant seated (eye level 4 feet above floor) at one end of the room, viewing the most remote luminaire at its proposed mounting height and location. See Fig. 11–5.

Preliminary results from research indicate that within the zone from 0 to 45 degrees from the line of sight in either a horizontal or vertical plane, the discomfort effect from the luminance of a large luminous area is relatively independent of its position in the field of view. Thus, similar luminance limitations can be applied to over-all ceiling lighting systems and to large window areas in the walls if they are apt to be viewed directly. Until the research is completed, it is suggested that the luminance of such large luminous areas should probably be well below the 250 footlambert uniform luminance limit of Fig. 11–4.

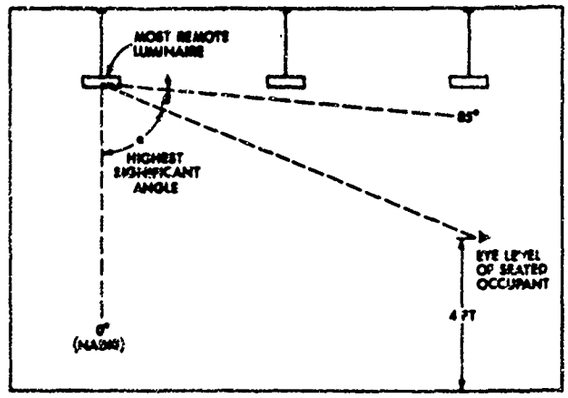


Fig. 11–5. *Critical glare zone.* In this illustration only the luminances within the zone of angle α can be seen by the occupant. The luminances within the zone of angle β will not be seen and therefore may be disregarded in evaluating luminance limitations.

Fig. 9-27. Brightness Factors

A. For Indirect and Luminous Ceiling Systems

To obtain average brightness on walls, ceilings or floor multiply average work plane illumination by appropriate factor.

Ceiling Reflectance*	0.80				0.70			0.50		
Wall Reflectance	0.80	0.50	0.30	0.10	0.50	0.30	0.10	0.50	0.30	0.10
ROOM COEFFICIENT	WALL (midway between floor and ceiling)						FLOOR REFLECTANCE—0.30			
0	0.52	0.33	0.20	0.07	0.33	0.20	0.07	0.33	0.20	0.07
0.1	0.54	0.33	0.20	0.07	0.33	0.20	0.07	0.33	0.20	0.07
0.2	0.55	0.42	0.20	0.07	0.34	0.20	0.07	0.34	0.20	0.07
0.3	0.57	0.35	0.21	0.07	0.36	0.21	0.07	0.35	0.21	0.07
0.4	0.58	0.36	0.21	0.07	0.36	0.21	0.07	0.36	0.21	0.07
0.5	0.60	0.37	0.22	0.07	0.37	0.22	0.07	0.37	0.22	0.07
0.7	0.63	0.39	0.23	0.08	0.39	0.23	0 08	0.39	0.23	0 8
1.0	0.66	0.43	0.26	0.09	0.43	0.26	0.09	0.43	0 26	0.09
	WALLS (midway between floor and ceiling)						FLOOR REFLECTANCE—0.10			
0	0.44	0.28	0.17	0.05	0.28	0.17	0.05	0.28	0.17	0.05
0.1	0.46	0.29	0.17	0.06	0.29	0.17	0.06	0.29	0.17	0.06
0.2	0.49	0.30	0.18	0.06	0.30	0.18	0.06	0.30	0.18	0.06
0.3	0.51	0.31	0.19	0.06	0.31	0.19	0.06	0.31	0.19	0.06
0.4	0.53	0.33	0.19	0.06	0.33	0.19	0.06	0.33	0 19	0.06
0.5	0.55	0.34	0.20	0.07	0.34	0.20	0.07	0.34	0.20	0.07
0.7	0.59	0.37	0.22	0.07	0.37	0.22	0.07	0.37	0.22	0.07
1.0	0.66	0.41	0.25	0.08	0.41	0.25	0.08	0.41	0.25	0.08
	CEILING						FLOOR REFLECTANCE—0 30			
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.1	1.07	1.11	1.13	1.15	1.11	1.30	1.15	1.11	1.13	1.15
0.2	1.15	1.23	1.28	1.33	1.23	1.28	1.33	1.23	1.28	1.33
0.3	1.24	1.36	1.45	1.53	1.36	1.45	1.53	1.36	1.45	1.53
0.4	1.32	1.51	1.64	1.76	1.51	1.64	1.76	1.51	1.64	1.76
0.5	1.42	1.68	1.86	2.03	1.68	1.86	2.03	1.68	1.86	2.03
0.7	1.63	2.08	2.39	2.70	2.08	2.39	2.70	2.08	2.39	2.70
1.0	1.99	2.86	3.48	4.14	2.86	3.48	4.14	2.86	3.48	4.11
	CEILING						FLOOR REFLECTANCF—0.10			
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.1	1.09	1.11	1.13	1.15	1.11	1.13	1.15	1.11	1.13	1.15
0.2	1.74	1.24	1.29	1.33	1.24	1.29	1.33	1.24	1.29	1.33
0.3	1.27	1.38	1.46	1.53	1.38	1.46	1.53	1.38	1.46	1.53
0.4	1.36	1.54	1.65	1.76	1.54	1.65	1.76	1.54	1.65	1.76
0.5	1.47	1.71	1.87	2.03	1.71	1.87	2.03	1.71	1.87	2.03
0.7	1.89	2.11	2.41	2.70	2.11	2.41	2.70	2.11	2.41	2.70
1.0	2.07	2.91	3.51	4.15	2.91	3.51	4.15	2.91	3.51	4.15
	FLOOR						FLOOR REFLECTANCE—0.30			
0	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
0.1	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29
0.2	0.29	0.28	0.28	0.27	0.28	0.28	0.27	0.28	0.28	0.27
0.3	0.28	0.27	0.27	0.26	0.27	0.27	0.26	0.27	0.27	0.26
0.4	0.27	0.26	0.26	0.25	0.26	0.26	0.25	0.26	0.26	0.25
0.5	0.27	0.25	0.25	0.24	0.25	0.25	0.24	0.25	0.25	0.24
0.7	0.25	0.24	0.23	0.22	0.24	0.23	0.22	0.24	0.23	0.21
1.0	0.24	0.21	0.20	0.19	0.21	0.20	0.19	0.21	0.20	0.19
	FLOOR						FLOOR REFLECTANCE—0.10			
0	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
0.1	0.10	0.10	0.10	0.09	0.10	0.10	0.09	0.10	0.10	0.09
0.2	0.10	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
0.3	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
0.4	0.09	0.09	0.09	0.08	0.09	0.09	0.08	0.09	0.09	0.08
0.5	0.09	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
0.7	0.08	0.08	0.08	0.07	0 08	0.08	0 07	0.08	0.08	0.07
1.0	0.08	0.07	0.07	0.06	0.07	0.07	0.06	0.07	0.07	0.06

*For luminous ceiling the apparent ceiling reflectances must be used. (Refer to Moon, P. and Spencer, D. E., "Interflections in Coupled Enclosures," *Journal of Franklin Institute*, August, 1950.)

Fig. 9-27. Continued

B. For Uniformly Diffusing Luminaires

To obtain average brightness on walls, ceilings or floor multiply average work plane illumination by appropriate factor.

Ceiling Reflectance	0.80				0.70			0.50		
Wall Reflectance	0.50	0.30	0.10		0.50	0.30	0.10	0.50	0.30	0.10
ROOM COEFFICIENT	WALLS (midway between floor and ceiling)						FLOOR REFLECTANCE—0.30			
0	0.25	0.22	0.13	0.04	0.21	0.13	0.04	0.18	0.11	0.03
0.1	0.79	0.44	0.27	0.09	0.45	0.27	0.09	0.48	0.29	0.10
0.2	0.71	0.46	0.28	0.09	0.46	0.28	0.10	0.49	0.30	0.10
0.3	0.71	0.47	0.29	0.10	0.48	0.29	0.10	0.50	0.31	0.10
0.4	0.73	0.48	0.30	0.10	0.49	0.30	0.10	0.51	0.31	0.11
0.5	0.74	0.49	0.31	0.11	0.50	0.31	0.11	0.52	0.32	0.11
0.7	0.76	0.51	0.33	0.11	0.52	0.33	0.12	0.54	0.33	0.12
1.0	0.79	0.53	0.36	0.13	0.54	0.36	0.13	0.56	0.35	0.14
	WALLS (midway between floor and ceiling)						FLOOR REFLECTANCE—0.10			
0	0.00	0.17	0.22	0.07	0.36	0.22	0.07	0.34	0.21	0.07
0.1	0.55	0.42	0.25	0.08	0.42	0.26	0.09	0.45	0.27	0.09
0.2	0.66	0.43	0.27	0.08	0.44	0.27	0.09	0.46	0.28	0.09
0.3	0.66	0.44	0.27	0.09	0.45	0.28	0.10	0.47	0.29	0.10
0.4	0.69	0.45	0.28	0 10	0.46	0.29	0 10	0.49	0.30	0.10
0.5	0.70	0.47	0.29	0.10	0.48	0.30	0.10	0.50	0.32	0.11
0.7	0.73	0.50	0.32	0.11	0.51	0.32	0.11	0.53	0.34	0.12
1.0	0.77	0.54	0.35	0.13	0.55	0.36	0.13	0.56	0.37	0.13
	CEILING						FLOOR REFLECTANCE—0.30			
0	0.68	0.68	0.68	0.5	0.54	0 54	0.53	0.43	0.43	0.43
0.1	0.64	0.63	0.63	0.63	0.59	0.59	0.59	0.48	0.48	0.48
0.2	0.69	0.69	0.69	0.69	0 64	0.64	0.64	0.52	0.52	0.52
0.3	0.74	0.75	0.76	0 76	0.69	0.70	0.76	0.56	0.56	0.58
0.4	0.78	0.81	0.83	0.85	0 75	0 76	0.85	0.60	0.61	0.63
0.5	0.82	0.86	0.90	0.94	0 80	0.83	0.94	0.64	0.65	0.70
0.7	0.89	0.96	1.05	1.13	0 90	0 97	1.14	0.72	0.74	0.83
1.0	0.99	1.17	1.31	1.48	1 00	1.20	1 48	0.83	0.88	1.06
	CEILING						FLOOR REFLECTANCE—0.10			
0	0.89	0.89	0.89	0.89	0.82	0.82	0.82	0.67	0.67	0.67
0.1	0.87	0.86	0.56	0 56	0.82	0.82	0.82	0.43	0.42	0.42
0.2	0.83	0.63	0.64	0.61	0 59	0.59	0.59	0.48	0.48	0.48
0.3	0.80	0.70	0.71	0.70	0.65	0.66	0.67	0.53	0.54	0.54
0.4	0.74	0.77	0.79	0.79	0.71	0.73	0.75	0.57	0.59	0.61
0.5	0.79	0.84	0.87	0.89	0.77	0 80	0.84	0.62	0.65	0.67
0.7	0.88	0.97	1.04	1.10	0.89	0.95	1.03	0.70	0.76	0.82
1.0	0.99	1.17	1.31	1.46	1.06	1.12	1.24	0.82	0.93	1.06
	FLOOR						FLOOR REFLECTANCE—0.30			
0	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
0.1	0.30	0.30	0.30	0.29	0.30	0.30	0.29	0.30	0.30	0.29
0.2	0.30	0.30	0.29	0.29	0.30	0.29	0.29	0.30	0.29	0.29
0.3	0.30	0.29	0.29	0.28	0.29	0.29	0.28	0.30	0.29	0.29
0.4	0.30	0.29	0.28	0.28	0.29	0.29	0 28	0.30	0.29	0.28
0.5	0.29	0.29	0.28	0 27	0.29	0.28	0.28	0.30	0.28	0.28
0.7	0.29	0.28	0.28	0.27	0.28	0.28	0.27	0.29	0.27	0.28
1.0	0.28	0.28	0.27	0.26	0.28	0.27	0.27	0.29	0.27	0 27
	FLOOR						FLOOR REFLECTANCE—0.10			
0	0.10	0.10	0.10	0 10	0.10	0.10	0 10	0.10	0.10	0.10
0.1	0.10	0.10	0 10	0 10	0.10	0.10	0.10	0 10	0.10	0.10
0.2	0.10	0.10	0.10	0.09	0 10	0 10	0 10	0.10	0.10	0.10
0.3	0.10	0.10	0.10	0 09	0.10	0.10	0 09	0.10	0.10	0.10
0.4	0.10	0.10	0.10	0 09	0 10	0.10	0 09	0.10	0.10	0 09
0.5	0.10	0 10	0.09	0.09	0.10	0.09	0.09	0.10	0.10	0 09
0.7	0.10	0.09	0.09	0 09	0.09	0.09	0.09	0.10	0.10	0.09
1.0	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.10	0.09	0.09

Fig. 9-27. CONTINUED

C. FOR DIRECT LUMINAIRES

To obtain average brightness on walls, ceilings or floor multiply average work plane illumination by appropriate factor.

Ceiling Reflectance	0.80				0.70			0.50		
Wall Reflectance	0.80	0.50	0.30	0.10	0.50	0.30	0.10	0.50	0.30	0.10
ROOM COEFFICIENT	WALLS (midway between floor and ceiling)						FLOOR REFLECTANCE—0.30			
0	0.22	0.14	0.08	0.03	0.13	0.08	0.03	0.11	0.07	0.02
0.1	0.33	0.19	0.12	0.04	0.19	0.11	0.36	0.18	0.10	0.03
0.2	0.34	0.20	0.12	0.04	0.20	0.11	0.36	0.19	0.11	0.03
0.3	0.38	0.21	0.12	0.04	0.20	0.11	0.36	0.19	0.11	0.03
0.4	0.38	0.22	0.12	0.04	0.21	0.12	0.37	0.21	0.12	0.04
0.5	0.41	0.22	0.12	0.04	0.24	0.12	0.38	0.22	0.12	0.04
0.7	0.42	0.25	0.14	0.04	0.25	0.14	0.43	0.25	0.14	0.04
1.0	0.50	0.33	0.19	0.06	0.33	0.19	0.60	0.33	0.19	0.06
	WALLS (midway between floor and ceiling)						FLOOR REFLECTANCE—0.10			
0	0.07	0.05	0.03	0.01	0.04	0.03	0.01	0.04	0.02	0.01
0.1	0.21	0.13	0.07	0.02	0.13	0.07	0.02	0.06	0.07	0.02
0.2	0.24	0.14	0.08	0.03	0.14	0.08	0.02	0.13	0.08	0.02
0.3	0.27	0.15	0.09	0.03	0.15	0.09	0.03	0.15	0.68	0.03
0.4	0.30	0.17	0.09	0.03	0.16	0.09	0.03	0.16	0.09	0.03
0.5	0.33	0.18	0.10	0.03	0.18	0.10	0.03	0.18	0.10	0.03
0.7	0.40	0.22	0.12	0.03	0.22	0.12	0.04	0.21	0.12	0.04
1.0	0.55	0.31	0.18	0.06	0.31	0.18	0.06	0.30	0.18	0.05
	CEILING						FLOOR REFLECTANCE—0.30			
0	0.23	0.23	0.23	0.23	0.21	0.21	0.21	0.15	0.15	0.15
0.1	0.25	0.23	0.21	0.20	0.20	0.19	0.18	0.14	0.13	0.13
0.2	0.25	0.21	0.19	0.17	0.19	0.17	0.15	0.13	0.12	0.11
0.3	0.26	0.21	0.17	0.14	0.18	0.15	0.13	0.13	0.11	0.09
0.4	0.28	0.20	0.16	0.12	0.18	0.14	0.11	0.12	0.10	0.08
0.5	0.30	0.20	0.15	0.10	0.18	0.13	0.09	0.12	0.09	0.07
0.7	0.34	0.21	0.14	0.08	0.18	0.12	0.07	0.13	0.09	0.05
1.0	0.44	0.36	0.16	0.07	0.22	0.14	0.05	0.16	0.10	0.05
	CEILING						FLOOR REFLECTANCE—0.10			
0	0.08	0.08	0.08	0.08	0.07	0.07	0.07	0.05	0.05	0.05
0.1	0.10	0.08	0.08	0.07	0.07	0.07	0.06	0.05	0.05	0.04
0.2	0.12	0.09	0.08	0.06	0.08	0.07	0.05	0.06	0.05	0.04
0.3	0.14	0.10	0.08	0.05	0.09	0.07	0.05	0.06	0.05	0.03
0.4	0.17	0.11	0.08	0.05	0.10	0.07	0.04	0.07	0.05	0.03
0.5	0.20	0.12	0.08	0.04	0.11	0.07	0.04	0.07	0.05	0.02
0.7	0.23	0.15	0.09	0.04	0.13	0.08	0.04	0.09	0.06	0.03
1.0	0.35	0.22	0.13	0.05	0.16	0.12	0.04	0.14	0.08	0.03
	FLOOR						FLOOR REFLECTANCE—0.30			
0	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
0.1	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
0.2	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
0.3	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
0.4	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
0.5	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
0.7	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.31	0.30	0.30
1.0	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.31	0.30	0.30
	FLOOR						FLOOR REFLECTANCE—0.10			
0	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
0.1	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
0.2	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
0.3	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
0.4	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
0.5	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
0.7	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
1.0	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10

APPENDIX B

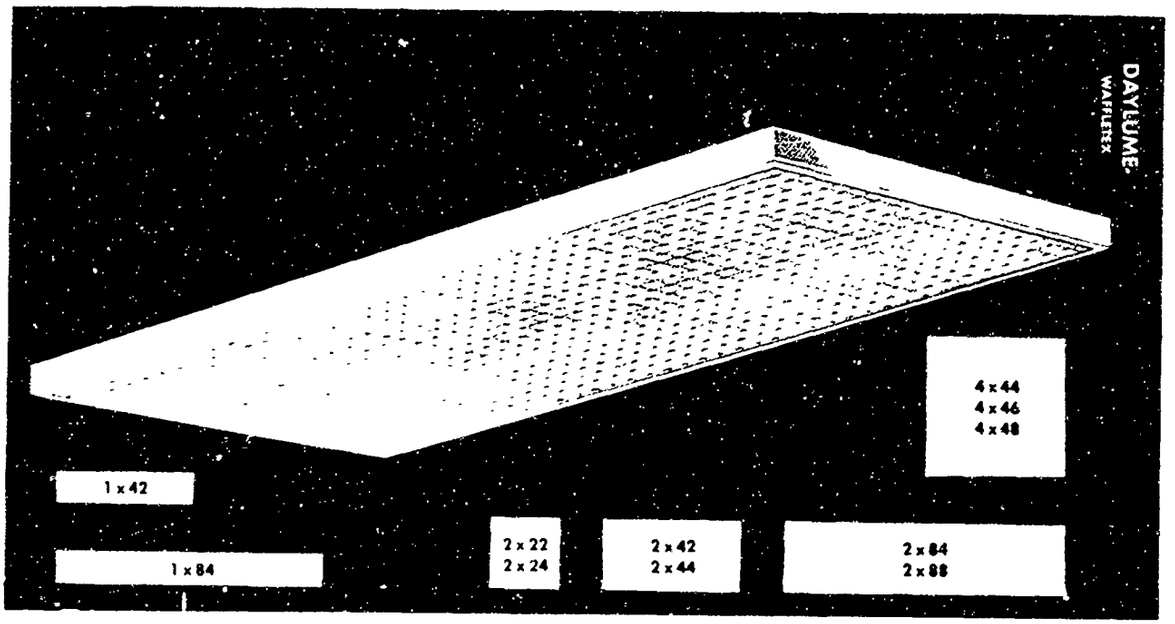
OTHER COMPONENTS CONSIDERED FOR ML-1A CONTROL CAB

Other lighting components considered for the ML-1A control cab lighting system are listed below, with component functions and reasons why they were unsuitable for this specific application.

Component	Function	Why Unsuited
1. Luxtrol type WBD-200	Dimmer control	5-40 watt lamps are maximum load.
2. Luxtrol type WBD-450	Dimmer control	Physical size too large for allowable mounting space in console.
3. General Electric DS3000	Dimmer control	Maximum light output is 50% of rated for an undimmed system's capability; GE DS5000 system provides approximately 100% of rated light output.
4. Smithcraft Dominaire series DMP/OMA	Luminaires for aisle and operator areas.	Maximum recess depth for luminaire is 1 1/4 inches. Lamp removal is not possible if the luminaire is recessed more than the above value.
5. Guth Company Cove type PSG6281	Luminaire for aisle area	Not compatible with workspace; i.e., highest chassis in equipment racks could not be pulled out, and exposed ends of luminaire would be hazardous to movement of personnel.
6. Slimline lamps	Lighting system lamps	Cannot be dimmed and are not compatible with workspace, i.e., interfere with escape hatch.

APPENDIX C

LUMINAIRE TECHNICAL DATA



SPECIFICATIONS

SCOPE: Shallow (3¼" depth) direct type luminaires for surface mounting To be suitable for end-to-end, side-by-side, or pattern installation arrangements Fixtures available in sizes for two, four, six, and eight F40 and two and four F20T12 lamps

ENCLOSURES: WAFFLETEX clear plastic enclosures provide low-brightness louvering combined with prisms to optically control the illumination and reduce brightness. Panels consist of a grid pattern of ¾" square louvers covered by the prismatic panel, molded in one piece. Supplied in 2' x 2', 2' x 4' and 1' x 4' panels

CONSTRUCTION: Fixture body to be 3¼" deep Sizes approximately 2' x 2', 2' x 4', 2' x 8', 4' x 4', 1' x 4', 1' x 8'. Backplate of body to be recessed ⅛" for minimum fixture contact with ceiling and maximum heat dissipation. Steel wiring cover shall conceal all wiring and ballasts and provide a cover for central feed into fixture. Knockouts to be located in ends and sides. All enclosures to be mounted in metal frames equipped with separable hinges and stainless steel spring-actuated trigger-latches

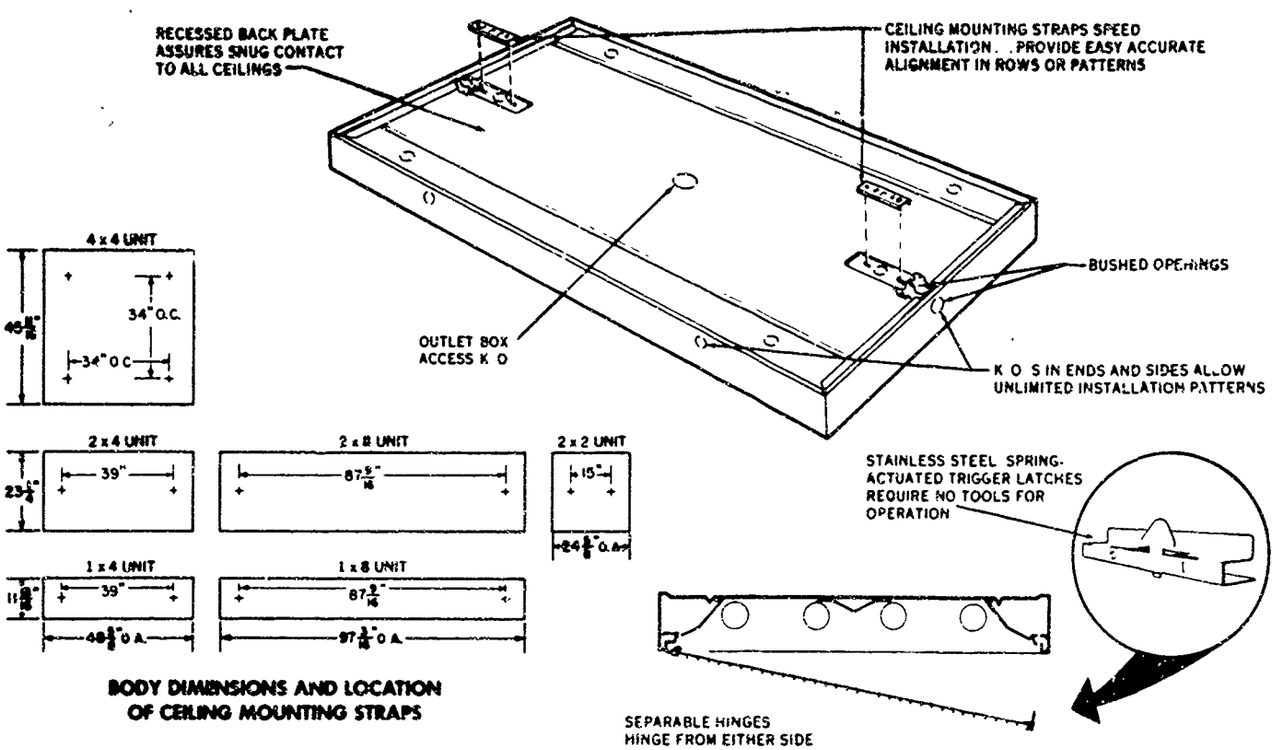
WIRING: Ballasts for 430-MA F40 lamps and Trigger-Start type 390-MA for F20T12 lamps to be individually protected and all electrical components to be replaceable without disturbing fixture in ceiling To be UL listed and carry Union wiring and fabrication labels

FINISH: All steel surfaces shall be pre-treated by a protective coating of zinc phosphate, applied in a five stage process. Final finish shall be Hot-Bonded baked white enamel.

INSTALLATION: Mounted direct to ceiling Mounting straps to be included for attachment of fixture to ceiling, singly, in rows or in patterns

Unit Size	Catalog No Body	Catalog No Eye	Description and Lamps	Body Dimensions	Approx Spg Wt
1 x 4	1 x 42	739	Two-Lamp, 4-foot Rapid-Start Unit	11 13/16" x 48 3/16" x 3¼"	34 lbs
1 x 8	1 x 84	739•	Two-Row Tandem, 4-foot Rapid-Start Unit	11 13/16" x 97 3/16" x 3¼"	67 lbs
2 x 2	2 x 22	389	Two-Lamp 2-foot Trigger-Start Unit	23¼" x 24 3/16" x 3¼"	30 lbs
2 x 2	2 x 24	389	Four-Lamp, 2-foot Trigger-Start Unit	23¼" x 24 3/16" x 3¼"	35 lbs
2 x 4	2 x 42	789	Two-Lamp, 4-foot Rapid-Start Unit	23¼" x 48 3/16" x 3¼"	43 lbs
2 x 4	2 x 44	789	Four-Lamp, 4-foot Rapid Start Unit	23¼" x 48 3/16" x 3¼"	48 lbs
2 x 8	2 x 84	789-P	Two-Row Tandem, 4-foot Rapid-Start Unit	23¼" x 97 3/16" x 3¼"	88 lbs
2 x 8	2 x 88	789-P	Four-Row Tandem, 4-foot Rapid Start Unit	23¼" x 97 3/16" x 3¼"	94 lbs
4 x 4	4 x 44	789D-P	Four Lamp, 4-foot Rapid-Start Unit	45 13/16" x 48 3/16" x 3¼"	78 lbs
4 x 4	4 x 46	789D-P	Six-Lamp, 4-foot Rapid-Start Unit	45 13/16" x 48 3/16" x 3¼"	83 lbs
4 x 4	4 x 48	789D-P	Eight-Lamp, 4-foot Rapid-Start Unit	45 13/16" x 48 3/16" x 3¼"	87 lbs

• Require Two Enclosures



BODY DIMENSIONS AND LOCATION OF CEILING MOUNTING STRAPS

ENGINEERING AND PHOTOMETRIC DATA

2' x 4' DAYLUME FIXTURE SPACING, 430-MA RAPID-START

ROOM SIZE	50 FOOTCANDLES			70 FOOTCANDLES			100 FOOTCANDLES		150 F C	200 F C
	2 LAMP UNITS	2 LAMP CONTINUOUS	4 LAMP UNITS	2 LAMP UNITS	2 LAMP CONTINUOUS	4 LAMP UNITS	2 LAMP CONTINUOUS	4 LAMP UNITS	4 LAMP CONTINUOUS	4 LAMP CONTINUOUS	4 LAMP CONTINUOUS
SMALL	5 x 8	9 ft	7 x 10		7 ft	7 x 7	5 ft	6 x 6	9 ft	6 ft	4 ft
MEDIUM	7 x 7	12 ft	9 x 10	6 x 6	9 ft	7 x 9	6 ft	6 x 7	11 ft	7 ft	5 ft
LARGE	6 x 9	14 ft	10 x 10	5 x 8	10 ft	7 x 10	7 ft	6 x 8	12 ft	8 ft	6 ft

NOTE Under no circumstances should spacings exceed SPACING MOUNTING RATIOS shown below

This data applicable for ML-1A Lighting System Luminaires

2 x 4 TWO LAMP 430 MA RAPID START DAYLUME 2 x 4 FOUR LAMP 430 MA RAPID START

NADIR C P 1710
3100 LUMEN LAMPS

SPACING MOUNTING RATIO
HEIGHT ABOVE WORK PLANE
1 35

MAINTENANCE FACTORS
Good 75 Med 70 Poor 65

Average Brightness in the 60° 90° zone from Nadir shall not exceed 530 Foot lamberts and/or or 350 Footlamberts respectively

CEILING	80%			50%			GLARE FACTOR	
FLOOR	30%		10%	30%		10%	END WISE	CROSS WISE
WALLS	50%	30%	10%	50%	30%	10%		
ROOM INDEX J	33	28	25	33	27	23	33	27	23	33	27	23	17	17
I	41	35	30	40	34	30	40	34	30	38	33	30	21	21
H	47	41	36	44	40	36	44	40	36	43	38	35	31	31
G	52	49	42	49	45	41	49	45	41	48	44	40	37	37
F	57	51	47	54	48	44	54	49	45	51	48	44	42	42
E	63	57	52	59	54	50	59	54	51	55	52	49	47	47
D	66	62	57	63	56	55	63	58	55	57	55	52	49	49
C	70	64	61	67	63	59	64	61	59	59	57	55	50	50
B	73	70	66	64	62	59	68	64	62	62	61	58	58	58
A	75	72	70	65	64	62	70	68	65	63	62	61	62	62

ZONAL INTERREFLECTANCE METHOD GLARE FACTORS BASED ON 50 FOOTCANDLE INSTALLATIONS

NADIR C P 3140
3100 LUMEN LAMPS

SPACING MOUNTING RATIO
HEIGHT ABOVE WORK PLANE
1 32

MAINTENANCE FACTORS
Good 75 Med 70 Poor 65

Average Brightness in the 60° 90° zone from Nadir shall not exceed 590 Foot lamberts and/or or 350 Footlamberts respectively

CEILING	80%			50%			GLARE FACTOR	
FLOOR	30%		10%	30%		10%	END WISE	CROSS WISE
WALLS	50%	30%	10%	50%	30%	10%		
ROOM INDEX J	30	25	21	29	24	21	29	24	21	29	24	21	29	29
I	37	31	27	35	29	25	35	29	25	33	28	24	36	36
H	42	36	32	40	35	32	40	35	32	38	33	30	50	49
G	47	42	37	45	40	36	44	40	36	43	39	35	59	58
F	50	45	41	47	43	40	45	44	40	44	42	39	66	66
E	55	50	47	50	47	44	51	48	45	49	46	44	74	74
D	58	53	50	52	50	47	54	50	48	50	49	47	82	80
C	60	56	53	54	51	48	56	53	50	52	50	49	84	82
B	64	60	57	56	54	52	58	56	54	54	52	51	96	94
A	66	63	60	57	55	54	60	58	56	55	54	53	101	99

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13 ABSTRACT

This report gives lighting criteria and lighting-system design methods for illuminating small-shelter interiors effectively. It summarizes the amounts of light (quantity) currently recommended for representative visual tasks, as well as the practices for controlling light (quality).

Then, to show how these lighting-design methods are actually applied, it describes a lighting system designed for the proposed control cab of a mobile low-power nuclear power plant. This lighting system was evaluated by making a lighting survey in a control-cab mock-up. The results showed the system satisfied the lighting criteria established for the shelter.

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13 ABSTRACT Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

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14 KEY WORDS Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.