Information Circular 9074

Underground Coal Mine Lighting Handbook

(In Two Parts) 2. Application

Compiled by W. H. Lewis

MARCH 3, 1849

UNITED STATES DEPARTMENT OF THE INTERIOR
Donald Paul Hodel, Secretary

BUREAU OF MINES
Robert C. Horton, Director

Library of Congress Cataloging-in-Publication Data

Main entry under title:
Underground coal mine lighting handbook.

(Information circular/United States Department of the Interior, Bureau of Mines; 9074)

Bibliographies.
Supt. of Docs. no.: I 28.27:
Contents: v. 1. Background—v. 2. Application.

1. Mine lighting. 2. Coal mines and mining.
I. Lewis, W. H. (William H.) II. Series: Information circular (United States. Bureau of Mines); 9074.

TN309.U47 1986 622'.47 85-26942

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

A	ampere	kW	kilowatt
°C	degree Celsius	lb	pound
c/s	cycle per second	lm/W	lumen per watt
°F	degree Fahrenheit	mA	milliampere
fc	footcandle	min	minute
fL	footlambert	nm	nanometer
ft	foot	pct	percent
ft^2	square foot	s	second
ft/s	foot per second	sr	steradian
h	hour	V	volt
h/d	hour per day	W	watt
in	inch	W/ft	watt per foot
in^2	square inch	yr	year
K	kelvin		

SELECTED CONVERSION FACTORS

Abbreviation	Unit of measure	To convert to—	Multiply by—
c/in^2	candle per square inch	candle per square meter	0.000645
		footlambert	.00221
c/m^2	candle per square meter	candle per square inch	1,550
		footlambert	.2919
fc	footcandle	lux	10.76
fL	footlambert	candle per square inch	452.4
		candle per square meter	3.426
lx	lux	footcandle	.092903

UNDERGROUND COAL MINE LIGHTING HANDBOOK

(In Two Parts)

2. Application

Compiled by W.H. Lewis[1]

ABSTRACT

This Bureau of Mines report and its companion report (Information Circular 9073) have been prepared as a complete reference on underground coal mine lighting. This report discusses system design criteria and procedures, data and specifications to aid in selection of suitable mine lighting hardware, and guidelines for system installation and maintenance. Topics include light measuring techniques and instruments, illumination regulations for underground coal mine environments and equipment, lamps and ballasts, available mine lighting hardware, design and evaluation of coal mine illumination systems, and installation and maintenance of a mine lighting system.

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INTRODUCTION

This Bureau of Mines report and its companion report, Information Circular 9073, have been prepared as a complete reference on underground coal mine lighting. The reports are intended to assist those persons who design, install, and/or maintain mine lighting systems in making appropriate decisions.

This report discusses system design criteria and procedures, data and specifications to aid in selection of suitable mine lighting hardware, and guidelines for system installation and maintenance. Topics include light measuring techniques and instruments, illumination regulations for underground coal mine environments and equipment, lamps and ballasts, available mine lighting hardware, design and evaluation of coal mine illumination systems, and installation and maintenance of a mine lighting system. The report provides information to insure an understanding of the numerous, complex, and interrelated factors that must be considered to design and implement a mine lighting system that will satisfy human needs for good vision and comfort.

The design of good lighting systems for underground coal mines is no easy task because of the unique environment and work procedures encountered in coal mines. The primary objective of these reports is, therefore, to identify the major problems encountered in this lighting application and to provide guidance in the solution of these problems. If they are carefully designed and implemented, lighting systems provide mine workers improved visibility and contribute to improved safety, productivity, and morale. Properly designed lighting systems can prove to be a very cost-effective investment for the mine operator.

This report was prepared by BCR National Laboratory (BCRNL), Monroeville, PA, under Bureau of Mines contract J0113063. The following contributed significantly to the production of the report: J. Yingling and K. Whitehead, BCRNL; A. Szpak, ADS Engineering and Design, Inc.; and personnel of the CIE Mine Lighting Committee, the Illuminating Research Institute, and Applied Science Associates, Inc.

CHAPTER 1.—LIGHT MEASURING TECHNIQUES AND INSTRUMENTATION

Lighting, from the viewpoint of engineering data and computations, is discussed in Bureau of Mines Information Circular (IC) 9073. Instruments are, however, required to evaluate lighting systems and components. The field of light measurement is called photometry, and the instruments used to measure lighting are called photometers.

Many types of photometers are available to measure light energy and related quantities, including illumination, luminance, luminous intensity, luminous flux, contrast, color, and visibility. The discussion in this report is limited to photometers used to measure illumination, E, and luminance, L, from which other quantities, such as reflectivity and luminous intensity, may be computed.

The photometer is one of the most important tools for illumination system design and evaluation. Specific uses for underground mine illumination system measurements are—

Verification of compliance with illumination and luminance specifications in the regulations;
Evaluation of illumination system design options;
Calculation of reflectance of mine and mine simulator surfaces;
Checking light distribution;
Checking illumination depreciation over time; and
Evaluation of discomfort and disability glare.

Before taking measurements with a photometer, care must be taken to insure that a luminaire or illumination system is in the proper condition to satisfy the purpose of the measurements. An adequate warmup period should be allowed for fluorescent, sodium vapor, and mercury vapor luminaires. For instance, the light output of some types of fluorescent luminaires can be twice as great as initial levels after a 30-min warmup period. The light output of some luminaires (especially incandescent) can vary widely with deviations in line voltage from nominal. Dirty luminaires, obstructions, or deviations in luminaire mountings and orientations from specifications can significantly alter illumination levels.

PORTABLE PHOTOELECTRIC PHOTOMETERS

The portable photoelectric photometer consists of a photocell that receives light and converts it into an electrical signal that is conditioned through an electrical circuit and is displayed on a visual meter. The meter reading is proportional to the light energy level received by the photocell.

Even the more simple and durable photometers are delicate instruments that can give highly erroneous results when improperly used or calibrated. Proper instruction in the use and calibration of photometers cannot be overstressed. Many factors can cause significant errors in the measurements in the very low light levels typical of underground coal mines. Photometers are available in a variety of models ranging from the low-cost, handheld units, which are very convenient but have limited accuracy and range, to more expensive, and more accurate but less portable units.

The following major factors affecting the accuracy of photometers should be understood and considered before purchasing and using a unit.

Photocell Characteristics

Photocells used in portable photometers have been improved significantly in the past few years. New design photometers that utilize silicon photocell technology have distinct advantages when compared with selenium photocell photometers. Silicon photocells are more stable and exhibit a more uniform (linear) response in output with a change in light level. Selenium photocells are more prone to change in calibration with time and also can exhibit a memory (hysteresis) effect when measured light levels vary significantly. When exposed to illumination, the output of photocells decreases over a period of time because of fatigue. Therefore, the meter should be exposed to the light level being measured for as long an adaptation period as necessary; i.e., until the meter reading stabilizes.

Color Correction

The response of the human eye (spectral luminous efficiency) for photopic (daylight) vision is shown in figure 1, along with the response curve for a typical uncorrected selenium photocell. Note that the response of the cell differs significantly from that of the eye. This difference would cause a significant error in the measurement of visible light if the cell were not color corrected. This problem is corrected by the placement of filters on the surface of the photocell, which adjusts the response of the assembly to closely match that of the human eye. The response of a color-corrected photocell is also shown in figure 1.

Cosine Correction

The response of a photocell changes as the angle of light impinging on its surface changes. At high angles of incidence, a greater portion of incoming light is reflected from the cell surface. This is because the reflectance of most surfaces increases as the angle of incidence increases. Also, the photocell support frame may prevent some light from reaching the photocell. Errors in light measurement caused by these factors alone may be as much as 25 pct. The problem is corrected by placement of a diffusing cover over the photocell as shown in figure 2. This cover adjusts the level of light received by the cell to the correct proportion for various angles of incidence. A screening ring is also provided on some designs to reduce the light passing through the raised edge of the diffuser at very high angles of incidence.

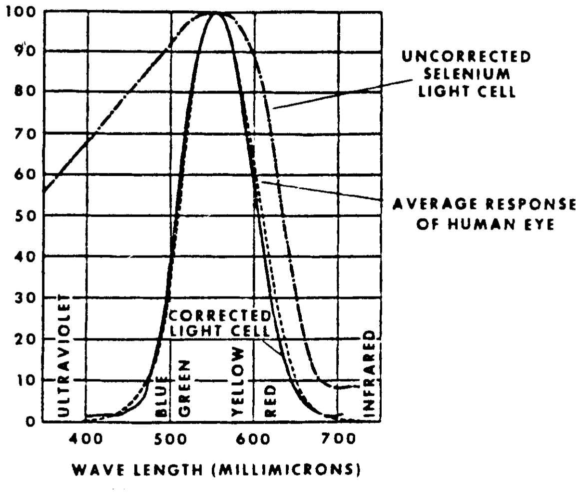

Figure 1.—Function of color correcting filter on response of photocells.

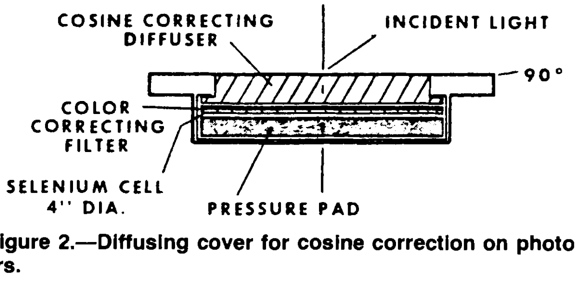

Figure 2.—Diffusing cover for cosine correction on photometers.

Sensitivity

Illumination and luminance levels in underground coal mines are very low. Regulations call for an average luminance of 0.06 fL and incident illumination levels in the range of 2.0 fc. Photometers used for the design and evaluation of underground coal mine illumination systems should have full-scale ranges to accurately display levels in these ranges. For instance, when using a meter with a full-scale range of 30 fc to measure a level of only 2 fc, just the zero adjustment and error in reading the meter can be very significant. Remember, the difference between a level of 1 to 2 fc means a 100 pct error in luminous energy. Overdesigning an underground mine illumination system to accommodate for poor instrumentation is an expensive alternative because of the relatively high cost of mine illumination system components. For the engineering design and evaluation of underground coal mine illumination systems, it is recommended that the photometer sensitivity be such that a full-scale range of no more than 0 to 3 fc is available. The meter should, of course, have other selectable ranges for higher level measurements, perhaps to 50 fc or greater. A meter with high sensitivity and accuracy permits the very necessary fine tuning of lighting systems needed to meet the stringent lighting regulations.

In designing mine lighting systems, luminance measurements are often required to determine the reflectance of the simulated mine surfaces. For luminance measurements, meters with an available full-scale setting of approximately 0 to 0.1 fL are recommended.

Purkinje Shift

When luminance levels occur that are below approximately 0.01 fL, the eye functions with only rod (scotopic) vision and the luminous sensitivity curve is shifted. This is called the Purkinje shift, which is discussed in IC 9073 (chapter 3). Photometers used in underground mine illumination are calibrated for rod and cone vision (photopic) because the 0.06-fL regulation is in the photopic range. Photometers that automatically compensate for the Purkinje shift are not currently available. For measurements below 0.01 fL, a photometer should be color corrected to match the scotopic luminous sensitivity curve.

Calibration

Calibration is a method by which the response of a photometer is set to match a working standard. Probably the most significant source of error in illumination measurements is inaccurate instrument calibration. Photometers are sensitive instruments that are susceptible to loss of calibration. Meter calibration should always be checked both before and after any series of light measurements.

Various types of standards are available or can be devised for calibration purposes. Most importantly, they must ultimately be traceable to a primary lighting standard in a national physical laboratory.

The following are suggested methods of maintaining a standard for photometer calibration.

The meter can be calibrated with the use of a precision calibration incandescent lamp specifically manufactured for this purpose. This must be done with accurate control of lamp voltage and according to procedures recommended by the lamp manufacturer. These lamps have limited life and should be used only as recommended by the supplier.

The working meter can be compared with a second reference meter that is periodically calibrated by the meter supplier. This reference meter would be used solely for calibration purposes. Use of the reference meter for other purposes would totally defeat its usefulness as a working standard.

The meter can be calibrated with a reference standard specifically designed by the manufacturer for the specific meter. These devices frequently employ nuclear standards.

Photometer Zeroing

It is important to check photometer zeroing prior to taking measurements. If an analog meter is used, this requires setting the meter reading to zero with the photocell completely covered. It should be verified that the meter remains correctly zeroed, when the photometer scale selector is changed. A photometer that cannot be properly zeroed on all scale ranges should be repaired and recalibrated. Improper zeroing can be the source of significant error in the low-coal mine illumination levels.

Temperature and Humidity Effects

Wide temperature variations affect the performance of photocells. Prolonged exposure of selenium photocells at temperatures above 120° F will permanently damage them. Silicon photocells are less susceptible to temperature variation when compared with selenium photocells. Exposure of a photometer to corrosive high-humidity conditions should be kept to a minimum. Photometers should certainly never be stored underground. Hermetically sealed cells provide greater protection from the effects of both temperature and humidity. It is recommended that a desiccator be packed with meters taken underground.

Contamination

In underground coal mines, dust can rapidly accumulate on the photodetector surface and diminish measurement accuracy. Moisture and dust can enter photometer enclosures and cause component corrosion or wear. These factors can easily affect the accuracy and useful life of an instrument. Photometers should be kept in a well sealed case and, to avoid contamination, should be removed only when they are to be used. The photodetector surface should be kept very clean, and care taken to use a cleaning method that will not scratch the surface.

Stray Light

Miner cap lamps can be a significant source of error in underground coal mine illumination system measurements. Care must be taken to insure that cap lamps do not contribute to surface luminance or impinge on the photodetector surface. It is best to turn off all cap lamps in the area when taking lighting measurements.

THE GO, NO-GO COAL MINE PHOTOMETER

Most photometers are *not permissible*, and, therefore, cannot be used inby the last open crosscut in underground coal mines. These meters are used only for the design and evaluation of illumination systems by engineering personnel.

The go, no-go photometer is a luminance level indicator developed and approved specifically for use by Mine Safety and Health Administration (MSHA) personnel to monitor the compliance of underground coal mine illumination systems. It is permissible and can therefore be used inby the last open crosscut. This meter provides a quick "go, no-go" indication to show whether the luminance of surfaces is below or above the 0.06-fL level required.

The go, no-go photometer is designed for convenient carrying by inspectors and other persons responsible for checking and/or maintaining light levels in compliance with regulations. Its size is 4.25 by 2.70 by 0.85 in, it is color corrected, and it has a calibration accuracy of ±0.1 pct. The lens' light acceptance angle is 26°, which allows the meter to average the surface brightness of a circular field 3 to 5 ft^2 in size when the meter is held 4 to 5 ft from the surface being measured.

The instrument contains a red emitting diode lamp that is activated if the measured luminance is below 0.06 fL and a green diode lamp that is illuminated if the measured luminance is greater than 0.06 fL.

The photometer can be calibrated by periodically returning it to the manufacturer or with the use of a tritium illumination standard (supplied by the manufacturer), which is traceable to the National Bureau of Standards. This standard has a natural life of 6 yr, after which time it must be returned to the manufacturer for replacement.

Complete procedures for the use of this instrument to evaluate the compliance of an illumination system are published by MSHA.[2]

MAKING ILLUMINANCE MEASUREMENTS

Considerable error in measurements can occur if the light meter photocell is not positioned correctly for the type of illuminance measurement being taken. In mine lighting, illuminance measurements are typically taken for the following purposes.

To determine the incident luminous energy (footcandles) on a surface.

To determine the light output characteristics of a luminaire.

To determine if illuminance levels are sufficient to qualify the illumination system for MSHA approval.

First of all, it is important to recognize that the photocell is designed to generate an output signal that is proportional to all the light impinging on it and passing through an imagined hemisphere below which the photocell is placed with the lens facing directly up. Therefore, if a measure of illuminance impinging on a surface is required, the photocell should be placed flat against the surface, as shown in figure 3*A*. This reading will yield the footcandles (lumens per square foot) of luminous energy that is intercepted by the surface.

When determining the candlepower distribution of a luminaire, the photocell should be pointed directly at the luminaire, as show in figure 3*B*. The candlepower curve can then be computed using the inverse square law, E =

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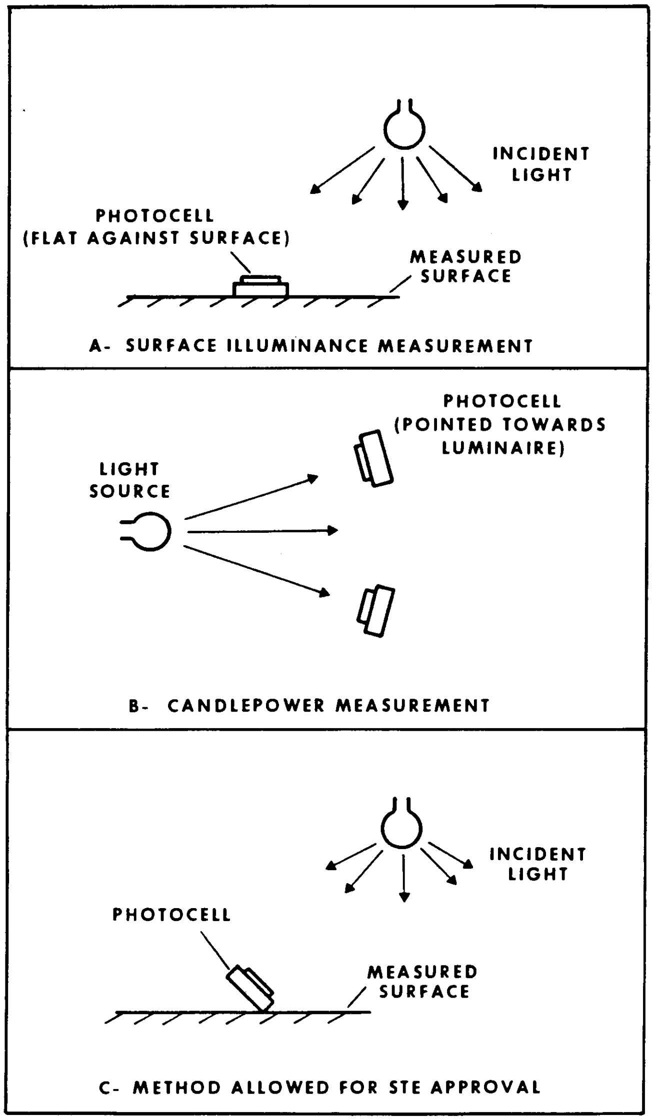
[2] Mine Safety and Health Administration. Handbook of Underground Coal Mine Illumination Requirements. 1980, p. 22.

I/D^2 where E is the measured illuminance; D is the distance to the luminaire, in feet; and I is the luminous intensity in candelas. Remember, when the distance from the photometer to the luminaire is less than five times the maximum luminaire dimension, this method rapidly becomes inaccurate. See the discussion of this law in IC 9073 (chapter 2).

When illuminance measurements are made to qualify a lighting system for a statement of test and evaluation (STE), MSHA allows them to be made by pointing the photocell in the direction that results in the highest measured value. This special case of measurement, as illustrated in figure 3*C*, yields the level of illuminance emanating in the direction of the photometer only. This measured illuminance does include the effect of the cosine law, which is discussed in IC 9073 (chapter 2), and, therefore, the values cannot be used for the computation of surface reflectance. This procedure is useful for STE measurements only. Detailed procedures for measurement and submittal of illumination levels to MSHA for lighting system approval are presented in chapter 2.



A- SURFACE ILLUMINANCE MEASUREMENT

B- CANDLEPOWER MEASUREMENT

C- METHOD ALLOWED FOR STE APPROVAL

Figure 3.—Photocell orientation for making illumination measurements.

MAKING LUMINANCE MEASUREMENTS

Luminance can be measured directly with photometers designed for this purpose. Typically, photometers have a luminance adapter as shown in figure 4. The adapter has a lens system that allows light within a specific cone angle to be sensed by the photocell.

One method specified for making luminance measurements of the face, roof, ribs, and floor with a photometer is specified in the Code of Federal Regulations, Title 30, part 75.1719-3. An alternative method of checking an illumination system for compliance by measurement of luminance is the go, no-go, photometer discussed previously. Luminance measurements specified in these regulations state that the photometer shall be held approximately perpendicular to the surface being measured. They also require that the sensing element be at a sufficient distance from the surface to allow the light sensing element to receive reflected light from a field not less than 3 ft^2 nor more than 5 ft^2. In areas where a photometer cannot be held a sufficient distance from the surface to encompass at least 3 ft^2, the luminance can be computed by averaging four uniformly spaced readings taken at the corners and within a square field of approximately 4 ft^2. In the evaluation of large surface areas, the meter can be used in a scanning mode, which requires the meter be held 4 to 5 ft from the surface being measured and moved in a direction parallel to the surface. The scan rate must be less than 3 ft/s to allow sufficient time for the sensor to react to changes in surface luminance. Such a procedure might be useful to mine operators to determine if they are in compliance with the lighting standards. The detailed regulations and procedures are discussed in chapter 2 and should be reviewed when luminance measurements are to be taken to establish compliance of a mine lighting system.

MAKING REFLECTANCE MEASUREMENTS

The total reflectance of a surface was defined in IC 9073 as $\rho = \phi$ reflected light/ϕ incident light, where ϕ reflected is the total reflected flux and ϕ incident is the total incident luminous flux.

Accurate measurements of the reflectance of surfaces such as a coal face can be a complex task because, when a surface is not a diffuser, the reflected flux can be scattered nonuniformly. Methods for the measurement of the reflectance of coal surfaces are briefly discussed in the following paragraphs. No standard method has been established for the measurement of coal reflectance.

The reflected-incident light comparison method is a convenient and simple means to measure reflectance if a surface is a good diffuser. For a perfect diffuser, reflectance can be computed using the equation $\rho = L'/E$. Although coal has a specular component in its reflective

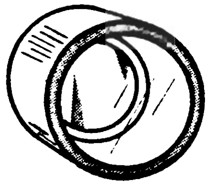


Figure 4.—Photocell fitted with adapter for luminance measurements.

characteristics, the cleaved surfaces are often not well oriented and, therefore, it may be considered a diffusing surface and for some purposes perfectly diffusing. A standard portable photometer equipped to measure both illuminance and luminance can be used in this method of reflectance measurement. Illuminance is measured by placing the photocell flat on a uniformly illuminated surface as shown in figure 5.

With the photometer in the luminance measurement mode, the surface luminance is measured and care is taken that the area being measured is within the conical acceptance angle of the luminance photodetector. Surface reflectance can then be computed with the preceding equation. This is the method utilized by MSHA to approve coal mine simulators, which must have a surface reflectance no greater than 5 pct. Note that measurement error is introduced when the surface is not a perfect diffuser. Also, care must be taken to insure that the presence of instrumentation or the operator does not interfere with the actual light levels.

The reflectance standard comparison method is a method by which the reflectance of an unknown surface is determined by comparing the luminance of a standard of known reflectivity to the luminance of the surface being tested. The reflectance of the surface being tested can be computed with the equation $\rho = \rho_s (L/L_s)$, where ρ is the reflectance of the surface being tested, ρ_s is the reflectance of the known standard surface, L is the luminance of the surface being tested, and L_s is the measured luminance of the standard surface. This method is depicted in figure 6. The acceptance angle of the photometer must be sufficiently small to insure that the measured luminance is within the area of the standard surface.

This method is adaptable to controlled laboratory measurement conditions because sample sizes need not be large. Commission Internationale de l'Eclairage (CIE) standard conditions for using this method state that the source of illumination shall be at an angle of 45° from the perpendicular to the surface to be tested and that viewing should be perpendicular to the surface.

The gonioreflectance method of reflectance measurement is one in which angles of incidence of light and viewing angles are varied to determine the spectral reflectance characteristics of a surface. A variety of test methods can be constructed to perform gonioreflectance measurements.[3]

OTHER MEASURING INSTRUMENTS

Many types of instruments are available for the purpose of evaluating lighting in the workplace. In addition to the physical photometers previously discussed, there are narrow field luminance meters and photographic photometers.

Luminance meters such as the Prichard photometer and spotmeters are available for the luminance measurement of small sources such as control panels, luminaire surfaces, and machine components for the determination of contrast levels and visibility. These meters are highly accurate devices used mainly for research and development purposes.

Photographic techniques can be used to measure luminance, contrast, and visibility, as well as to maintain a permanent record of conditions. Considerable care must be used to insure that the photographic process has the same spectral response as the eye and that the recorded scene depicts the observed and measured conditions.

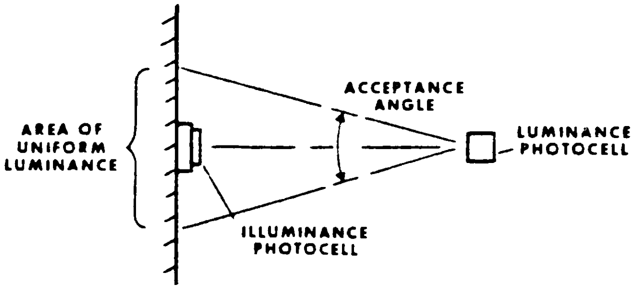


Figure 5.—Reflected-incident light comparison method for measuring reflectivity.

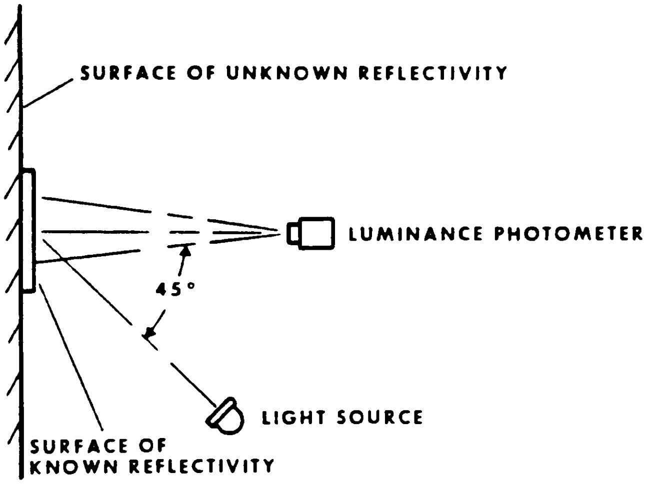


Figure 6.—Luminance standard comparison technique for measuring reflectivity.

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[3] Trotter, D. Reflectance Measurements in Mining.
Hitchcock, L. C. Development of Minimum Luminance Requirements for Underground Coal Mining Tasks.

CHAPTER 2.—ILLUMINATION REGULATIONS FOR UNDERGROUND COAL MINE ENVIRONMENTS AND EQUIPMENT

This chapter consolidates and explains the regulations, interpretations, and official enforcement policies that govern the implementation of lighting in underground coal mines in the United States. Note that it does not discuss regulations governing illumination component design, which are discussed in chapter 4.

These regulations are found in or referenced in part 75.1719 of the Code of Federal Regulations (CFR). They have four major thrusts:

1. Specification of required illumination levels and the particular areas of the mine that must meet these levels. (75.1719-1)
2. Specification of standards (primarily electrical) to be observed when implementing lighting systems to prevent the systems from posing additional hazard to worker or machine. (75.1719-2)
3. Specification of procedures for making light measurements to verify compliance with the illumination standards. (75.1719-3)
4. Specification of requirements, in addition to illumination, to increase visibility in the mine environment. (75.1719-4)

THE PRIMARY ILLUMINATION STANDARD AND ITS BASIS

> It must be borne in mind that published lighting values are not the complete answer to the problem they are meant to help solve, for whenever a stage of knowledge is reached upon which a code is based, unsolved problems still remain.[4]

This statement may be applied, of course, to the U.S. lighting regulations. Anyone implementing a lighting system on the basis of these regulations should not view the standards as a "cookbook prescription" for optimum lighting. Rather, these standards are only intended to specify *minimum* requirements for meeting the *priority* visual needs of the mine-face situation. The status of current knowledge and the necessary accommodations to account for variability of mining circumstances make specification of more extensive standards, at least for the present, inappropriate. To realize the optimum benefit from mine lighting, it may be desirable to exceed these minimum requirements in some instances and to consider additional factors. A thorough discussion of design considerations is presented in chapter 5, "Design and Evaluation of Coal Mine Illumination Systems."

The "cornerstone" of the U.S. lighting code is expressed in provision 75.1719-1(d) of the CFR. "The luminous intensity (surface brightness) of surfaces that are in a miner's normal field of vision of areas in working places that are required to be lighted shall be not less than 0.06 footlamberts. . ."

The following points should be noted about this specification.

1. The requirement is expressed in terms of luminance rather than illuminance. This is the preferred method of expressing standards since only the physical measure of luminance correlates the what the eye sees (see IC 9073, chapter 2). Moreover, by specifying luminance rather than illuminance, the standard is, theoretically, uniform regardless of variability in environmental reflectivity. The disadvantages of expression of standards in luminance terms is that (1) luminance measurements are more difficult to make, and (2) design requires accurate knowledge of reflectivity.
2. The statement that 0.06 fL applies to "surfaces that are in a miner's normal field of vision" is an explicit recognition that mine lighting should accommodate peripheral vision. As noted in IC 9073, chapter 3, peripheral vision is important in mining for (1) early recognition of conditions that might give prewarning of potential safety hazards in the peripheral field and (2) performance of tasks that require knowledge of the relative spatial relationships among objects separated by significant distance in the surroundings. Light on all surfaces in a miner's normal field of vision eliminates the "tunnel vision" effect of the narrow cap lamp beam and overcomes beam cutoff by machine structure or posts. Provision that this light illuminates these surfaces to 0.06 fL insures response of all the eye's photoreceptors to light impulses in the observer's field of view, particularly in the peripheral field (see IC 9073, chapter 3).
3. Research shows that the 0.06-fL level is adequate for performance of a major portion of mining tasks (fine perception of details is generally not required). Most of those tasks where greater levels are desirable are performed at close range and the cap lamp acts as a supplement to the general lighting for adequately meeting these lighting requirements.
4. The 0.06-fL general level of luminance is low enough that adaptation problems in going from the illuminated area to darker areas of the mine are not severe.

APPLYING THE ILLUMINATION STANDARD IN THE MINE ENVIRONMENT

The Federal coal mine lighting standards apply to all self-propelled mining machines utilized inby the last open crosscut. The reason for requiring illumination around these machines and in this area of the mine, as opposed to other machines and other areas of the mine, is because here is where (1) machine-worker activity is most concentrated and (2) hazards are most serious and most likely to develop.

The standards are expressed in terms of specific machine vicinities to be lighted to a surface brightness of at least 0.06 fL. These vicinities vary, depending upon machine type, mining method, and seam height. They have been selected primarily on the basis of the objectives stated previously; i.e., lighting needs for adequate peripheral vision and adequate visibility for task performance and hazard identification.

The specific machine vicinities to be illuminated to the 0.06-fL standard are identified in CFR 75.1719-1(e) (1) through (e)(6). In enforcing these standards, certain accommodations have been made by the Mine Safety and Health Administration (MSHA), so that the effective standards

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[4] First work cited in footnote 2.

are consistent with the current status of mine lighting technology. The accommodations are in recognition of problems with discomfort glare, hardware maintenance, efficient utilization of fixture candlepower, etc., which currently cannot be alleviated through system design and installation with available hardware and techniques. Policy in enforcing the illumination standards is based upon extensive and continuing postaudit of the impact of the standards and reflects a commitment by MSHA as a proponent of both good and practical lighting within the intent and scope of CFR 75.1719.

Appendix A identifies the standards that apply to the various machines and environments, the latest enforcement policies for these standards, and explanatory comments.

In complying with these standards, the mine operator has the option of mounting luminaires on the machine or separate from the machine, for example, temporarily mounting them along roof and ribs. The latter option is typically referred to as "area-lighting." Because of practical difficulties with area-lighting systems, nearly all systems now utilized employ machine-mounted fixtures. Area and machine-mounted systems are compared in detail in chapter 6.

The seam height used for lighting application requirements at a mine is equal to the normal extracted height. In cases where entry dimensions vary across the entries of a working section, the lowest dimension may be used to determine the lighting requirements that apply to that situation. On sections where the seam is extracted in two or more lifts (e.g., the upper 10 ft and lower 10 ft of a 20-ft seam), the lighting system must meet the requirements for both seam heights.

In addition to the illumination of face machine vicinities, it is a Federal requirement that each person who goes underground wear an approved personal cap lamp.

ADDITIONAL STANDARDS FOR IMPLEMENTING FACE ILLUMINATION SYSTEMS

Implementation of lighting systems at the coal mine working face presents considerable potential for creation of additional hazard or risk to personnel and equipment. Because of this, it has been necessary to establish additional standards to guide such implementation. The scope of this section is limited to those standards presented or referenced in CFR 75.1719-2, which affect MSHA approval of a lighting system design as implemented by a mine operator.

Electrical Requirements

The purpose of the electrical standards is to insure that lighting systems are implemented in such a manner that prevents creation of electrical shock, fire, or methane-dust ignition hazard.

First and foremost, CFR 75.1719-2(a) requires that all lighting fixtures and components utilized on face illumination systems be permissible. This means that (1) system components must be "certified" in accordance with the provisions of part 26 of the CFR or other parts referenced therein and (2) *systems* synthesized from these certified components must receive a Certificate of Approval for permissibility in accordance with part 26. The latter involves assuring compatability of the certified components and a check that certified components are used when necessary. The provisions of part 26 are discussed in detail in chapter 4. These design criteria are directed at hazards such as ignition of methane-air mixtures, excess surface temperature of components, electrical shock, etc., and their purpose is to assure that design of the individual components and the total system is adequate for safe implementation in a coal mine.

Note that the application of diffusers on luminaire lens may alter the permissibility of these components (depending upon the resulting heat dissipation characteristics and the chemical compatibility of the diffuser with the lens material). Approved diffusion materials include Teflon[5] fluorocaron polymer, Kapton polyimide film, Myler polyester film, nylon film of various thicknesses, sandblasted polycarbonate, and spray-on frostings. Diffusion materials should be approved in combination with a particular luminaire. MSHA maintains an updated list on such approved combinations.

In addition to this general requirement for utilization of permissible components and systems, there are some supplemental electrical standards, primarily directed at preventing the system from posing an electrical shock hazard, which must be incorporated in proposed lighting systems. These standards differ for two different classes of lighting systems defined as follows:

Machine mounted.—Lighting fixtures are permanently mounted upon mining machinery and power for the lighting system is derived from a power source on the machine.

Stationary.—Lighting fixtures are mounted independent from the machine and power is supplied to the fixtures through trailing cables. Longwall, shortwall, and area lighting systems fit into this category.

The reason for this differentiation is that (1) personnel are much more likely to come in bodily contact with stationary lighting fixtures while the fixtures are energized and (2) stationary fixtures are not in contact with an electrically grounded medium as are machine-mounted fixtures (i.e., the machine frame). Hence, stationary systems present a greater risk of causing electrical shock and more stringent precautions are warranted.

Supplementary Standards Applicable to Stationary Lighting Systems

Maximum Voltage Restriction (75.1719-2(c)(2)).—To reduce shock potential, the voltage on power systems supplying alternating current fixtures is limited to 70 V phase-to-neutral (i.e., 120 V phase-to-phase). This is the standard voltage used on all available longwall lighting systems. The limit on dc fixtures is 300 V. The latter restriction might apply in application of an area lighting system in a dc mine.

Grounding Requirements (75.1719-2 and 75.701).—All stationary ac lighting systems that provide power to the lighting fixtures and/or system power conditioning units at voltages greater than 100 V phase-to-phase (applies to all currently available longwall light systems) must incorporate a "resistance-grounded-neutral" grounding circuit which limits fault current to less than 5 A. Also, the size of the ground conductor in all cables must

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[5] Reference to specific products does not imply endorsement by the Bureau of Mines.

equal the cross-sectional area of the power conductor for 8 AWG or smaller power conductors or one-half the cross-sectional area of the power conductors 6 AWG or larger. Most lighting systems in use employ 8 AWG or smaller cable and, hence, require the same size ground conductor as the power conductor. Finally, the current rating of the ground-fault resistor must meet Institute of Electrical and Electronics Engineers (IEEE) specification 32-1972 for "extended time rating." (Specification is available from any MSHA District or Subdistrict office.) This is to insure that the grounding circuit is capable of maintaining low fault current for extended time periods should the protective circuitry which monitors ground faults fail to deenergize the circuit.

The circuit of figure 7 shows advantages over other grounding circuits (e.g., same circuit without a grounding resistor) in the event of a ground fault (short circuit between line and neutral) by (1) maintaining low current flow after the fault occurs and (2) maintaining metal parts in contact with the fault at low potential minimizing the shock hazard. The same circuit is required for all portable mining equipment, except that the current restriction is smaller for stationary lighting systems. The resistor is sized using Ohm's law—R equals V line to neutral divided by I maximum; 70 V/5 A or 14 ohms. Some designs employ slightly larger resistors, which would reduce the ground fault current below 5 A.

Trailing Cable Requirements (75.600-75.607).—Cables to stationary lighting systems (includes longwalls) are considered trailing cables and therefore all statutes of CFR 75, Subpart G, "Trailing Cable," apply to use of these cables. These statutes, which will not be discussed in detail here, address jacket flame-resistance, circuit protection, splicing, and procedures for breaking connections.

Circuit Breakers, Circuit Breaker Settings (75.1719-(2)(e) and 75.601-1).—A circuit breaker, or other approved device, must be utilized to protect the circuit from overloads and short circuits (e.g., damage of insulation). The instantaneous current setting at which the circuit breaker deenergizes the circuit is also specified. When stationary (longwall) systems are field inspected prior to issuance of a system acceptance (discussed later), a demonstration that the breaker is properly working is required. The following is a discussion of the method for determining the circuit breaker setting.

Breaker settings must comply with two criteria in the CFR:

1. 75.601-1.—Maximum allowable instantaneous circuit breaker settings are specified for trailing cables dependent on conductor size, as given in table 1.
2. 75.1719-2(e).—Maximum allowable instantaneous circuit breaker setting should not exceed one-half the available fault current.

Table 1.—Trailing cable maximum allowable circuit breaker instantaneous settings, amperes

Conductor size, AWG	*Setting*	*Conductor size, AWG*	*Setting*
14	50	8	200
12	75	6	300
10	150		

The criterion that yields the lowest ampere setting dictates the breaker setting of the particular lighting system in question.

Determination of the setting that complies with the first criterion is straightforward and involves simply reading from table 1 the setting that corresponds to the *minimum* size cable in the circuit protected by that breaker.

The following formula is accepted for determining the breaker setting in accordance with the second criteria: Maximum breaker setting = $I_{\min\phi\phi} = 0.5\,[(K_B \cdot E_{\phi\phi})/R_T]$.

$I_{\min\phi\phi}$ is the minimum allowable fault current, phase-to-phase, in amperes.

K_B is the breaker "tolerance factor" dependent on type of breaker utilized in the system, as follows:

Breaker type	K_B
1. Current transformer (CT), relay and contactor	0.90
2. "Mine duty" breaker (manufacturer specifies tolerance of low and high instantaneous settings to be ±10 pct of nominal setting) . .	.85
3. Standard breaker	.70

$E_{\phi\phi}$ is the voltage, phase to phase.

R_T is the cable resistance of the continuous current path to any termination that yields the highest total resistive value (this would correspond with the minimum fault current).

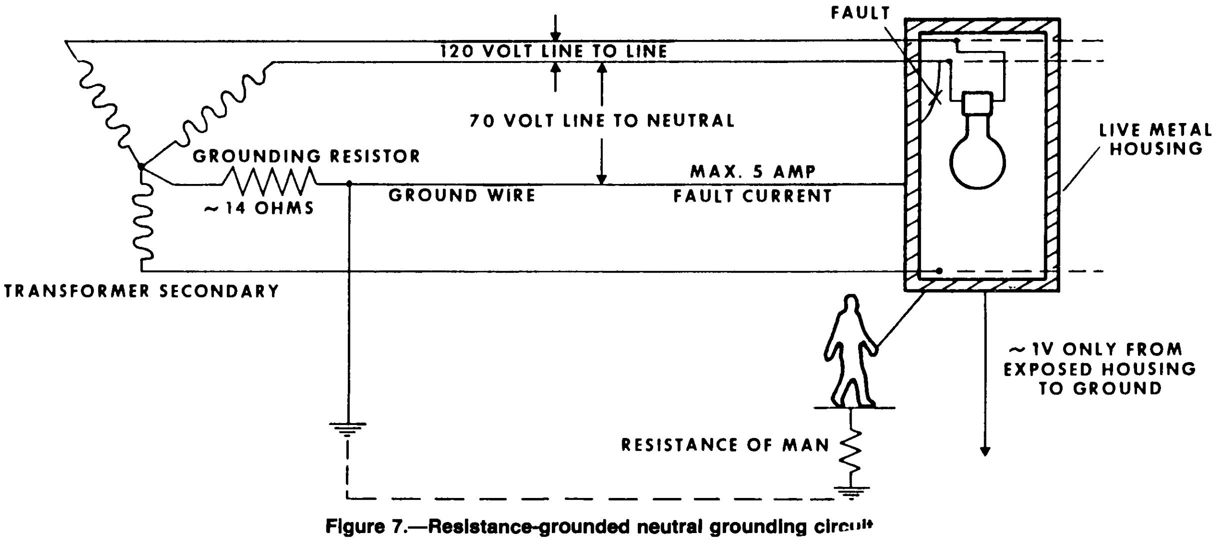


Figure 7.—Resistance-grounded neutral grounding circuit

R_T may be calculated knowing the size and length of trailing cable utilizing the values shown in table 2.

Table 2.—Conductor resistance based on conductor size, ohms per thousand feet

Conductor size, AWG	Resistance	Conductor size, AWG	Resistance
14	3.4	8	0.878
12	2.14	6	.552
10	1.35		

The basis of this relationship is Ohm's law, I = E/Z, used in all standard fault current analyses. In the case of stationary lighting systems, other impedances such as cable inductance and transformer primary and secondary impedance are insignificant relative to the magnitude of conductor resistance, R_T. The constant, 0.5, is the required safety factor specified in 75.1719-2(c).

As an example, a typical longwall system might use 785 ft of 8 AWG cable protected by a standard breaker to distribute power to power conditioning units along the face, as depicted in figure 8.

The first criterion yields a maximum breaker setting of 200 A, which corresponds with utilization of minimum size 8 AWG conductors (see table 1).

Applying the formula for the second criterion: Maximum breaker setting = $I_{min\phi\phi}$ = $0.5[(K_B \cdot E_{\phi\phi})/R_T]$; $0.5\,[(0.7)(120)/(785)(0.878/1000)]$ or 61 A. The second criterion yields the lowest breaker setting, hence, it controls the maximum setting permitted for this particular system design.

Supplementary Standards Applicable to Machine-Mounted Lighting Systems

Grounding Requirements.—Lighting fixtures in contact with the machine frame are electrically grounded through the machine grounding system. However, there is considerable potential for such fixtures to be severed from the machine and in such a state would be ungrounded, presenting a shock hazard. For this reason a separate ground conductor from the fixture housing to the machine main frame is required. The preferred method of doing this is to utilize a cable with a separate ground conductor in the supply cable to the fixture and to tie the fixture to the grounded lighting power supply or power distribution box. At the time the illumination standards were first implemented certain machines, especially shuttle cars, utilized only two-conductor cable to supply power to the already existing luminaires. Since substitution of a three-conductor cable, with ground wire, would involve extensive modifications, an external grounding shunt from a luminaire to the machine frame is permitted as a temporary measure. The two-conductor cable is to be replaced upon the next machine rebuild.

Intrinsically Safe Pilot Circuits on Explosion-Proof Connector Equipped Systems

For ease of maintenance, many explosion-proof lighting systems, both stationary and machine-mounted, now employ explosion-proof connectors at strategic locations to permit quick disconnect of system components (luminaires and power supplies) without disturbing packing glands. If such connectors are uncoupled while energized, the leads will be exposed, which creates a hazardous condition. Intrinsically safe pilot circuits as discussed in the following paragraph, can be used to deenergize the circuit branch feeding power to the connector and eliminate such a possibility of exposed and energized leads. Use of such circuits on explosion-proof connector equipped systems is required in some States and is highly recommended regardless of where the application is made.

An intrinsically safe pilot circuit is typically a modification of a ground check circuit that is used to monitor continuity of the ground conductor. A transformer places a low, intrinsically safe potential across a circuit formed by an additional conductor called a pilot wire shunted to the ground conductor (see figure 9). A relay monitors current in this loop and will deenergize the entire circuit if the current reaches zero (indicating continuity is broken). If the pin and socket arrangement shown in figure 9 is used for the internal connections within the connector, the pilot circuit will be broken first, tripping the relay and deenergizing the circuit before power leads A and B are exposed. (On systems without ground fault, monitoring will require a separate circuit which runs with the power cabling.)

Antiflicker Requirements

The potentially harmful effects of flickering light sources have been discussed in IC 9073 (chapter 3).

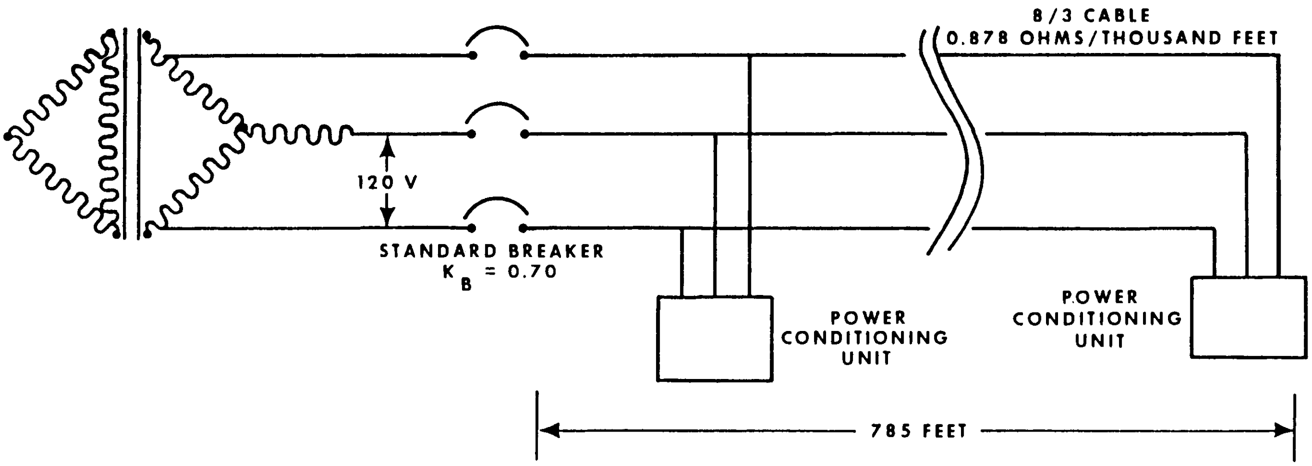


Figure 8.—Longwall power distribution circuit for breaker setting calculation.

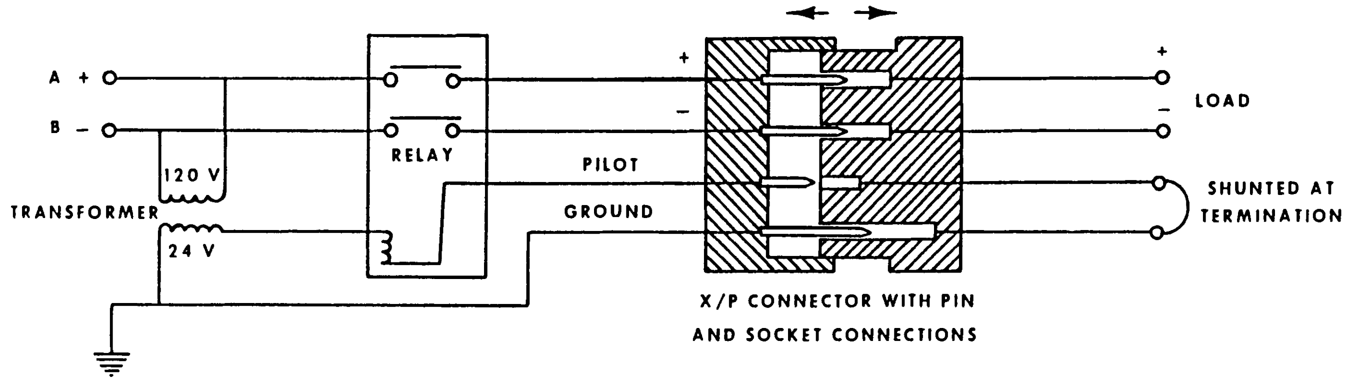


Figure 9.—Intrinsically safe pilot circuit with explosion-proof connector.

75.1719-2(c) requires lighting fixtures to be operated at power greater than 50 c/s. This would create a flicker of 100 pulses per second on arc discharge lamps which is beyond the threshold for human perception. This is generally not a problem since most light sources operate at 60 c/s from utility power or at much higher frequencies when solid state ballasts (see chapter 3) are used.

Requirements Concerning Luminaires in a Blasting Zone

To prevent the possibility of lighting circuitry initiating an explosion, all circuits to light fixtures in a zone where shooting is to occur (typically on longwalls) must be deenergized prior to removing shunts from the blasting caps. In addition, to prevent the blast from damaging the fixtures—perhaps voiding permissibility characteristics of the luminaires through lens damage or an electrical fault—one of the following two measures must be taken:

1. Fixtures located within 50 ft of the area where the shot is being fired must be removed.
2. Fixtures within this area must be protected against flying debris (e.g. by hanging belting).

From a maintenance viewpoint, the second option is often not desirable. Guards, such as suspended belting, can protect the fixtures from flying debris and maintain the integrity of the fixture housing. However, they offer little protection against shot percussion, which can damage luminaires internally, particularly fluorescent lamps. It is recommended that connector equipped longwall lighting systems be equipped with a quick-release mounting system (see chapter 6) to allow removal, rather than guarding, of at least those luminaires in the immediate shot vicinity.

Antiglare Requirements

It is a requirement that illumination systems be designed and installed to minimize discomfort glare. Concrete standards for realizing this do not exist at this time; however, it is recommended that a system be reviewed with respect to the following criteria, which represent some of the most significant glare problems:

1. Fixtures should not be mounted under canopies without backshielding.
2. Headlights and other directional luminaires should not be located behind machine-operator stations where the operators would be looking back into them. In particular they should not be applied on the front of the bolter.
3. Any fixture within the operator's line of sight, when he or she is performing routine tasks at the operator's station or machine control area, should be shielded and/or acceptably diffused.

MSHA STE PROGRAM

It is the responsibility of each mine operator to—

1. Meet the relevant standards for illuminating each workplace as specified in appendix A; and
2. In doing this, utilize systems that comply with the supplementary system-design standards outlined in the previous subsection.

The Statement of Test and Evaluation (STE) program has been established by MSHA to facilitate compliance with these two requirements.

The STE program is administered by MSHA's Approval and Certification Center (A&CC), a group that approves products and systems for use in underground mines. Lighting system design and application data are submitted to the A&CC group by system designers, including manufacturers and mine operators. This information is reviewed to determine system compliance with relevant requirements of the CFR and, if these requirements are satisfactorily met, A&CC issues an approval, called a statement of test and evaluation (STE), to the party submitting the design for review.

Mine operators may then implement the design in their mines and be guaranteed compliance with the illumination standards as long as the approved design and application specifications are initially and continually met in the actual installation. This includes proper maintenance of the system with respect to permissibility, cleanliness, and operativeness of system components.

An important aspect of the STE program is that the light measurements used in issuance of an STE approval may be obtained from an approved simulated mine environment using simulated models, or mockups of mining machinery. The following are benefits of this process.

1. The measurements obtained in the simulated environment are assumed applicable for any actual mine utilizing the given equipment and within the dimensional

restraints established in the simulator. Hence, an approval is given on the basis of a particular machine model and entry size and is independent of a particular mine.

2. The actual design process is simplified because it is conducted in a controlled environment where measurements are easily taken, and variations in layouts are easy to establish and test.

3. Access to a mine is unnecessary. This makes it convenient for independent firms with expertise in lighting, such as lighting hardware manufacturers and mining machinery manufacturers, to establish system designs on behalf of the mine operators.

VALUE OF THE STE PROGRAM TO MINE OPERATORS AND SOME IMPORTANT LIMITATIONS

Before continuing, it should be realized that an installed lighting system need not have an STE approval to be in compliance; there is no requisite for an STE in the CFR. However, it is generally to the mine operator's advantage to purchase systems that already have an STE approval or to obtain an STE approval for a design that does not have one.

The primary advantage of an STE-approved design over a non-STE-approved design is that the STE is a substitute for on-site light measurements in determining Whether the system is in compliance with the illumination requirements. An inspector *will not* take light measurements if—

1. *The inspected installation meets the approved design and application specifications*; i.e., machine-model number and its actual geometric configuration correspond with those given in the STE, luminaires are located and oriented as shown on the STE within specified allowable tolerances, and the system is being operated in entries with dimensions within the limits specified on the STE; and
2. *The inspected system is properly maintained*; i.e., all luminaires are operable, and the lens on all fixtures are clean permitting full transmission of light.

On a non-STE-approved system, light measurements *will* be taken to determine if the system complies with the lighting standards. Moreover, inspectors may elect to repeat these measurements on any future inspection, particularly in instances where entry dimensions, or other variables that may affect realized luminance levels, change.

For practical reasons, light levels on simulator-designed systems are verified using illumination (footcandle) rather than luminance (footlambert) measurements. This involves *assuming* a uniform reflectance of coal which then applies to all simulator designed systems. The reflectivity of coal specified in the regulations is 4 pct, which results in an illumination requirement of 2 fc to achieve a luminance of 0.06 fL (this derivation is explained at the end of this section). Actual fresh coal reflectivities have been reported from as low as 1 pct to as high as 10 pct (4 pct was representative).

A higher reflectivity in a particular mine would give the designer more flexibility in sizing, locating, and diffusing luminaires if an STE were not obtained, since, in this case, compliance would be assessed on the basis of on-site luminance measurements that account for the higher reflectivity. The operator wishing to design a system using actual reflectivity must consider the more rigorous inspection of non-STE-approved systems and that "just meeting but not exceeding" 0.06 fL is not necessarily a priority or, in some cases, even appropriate design objective.

Mine operators should also consider that if improper maintenance, e.g., dirty lens, results in the necessity of on-site measurements of an STE-approved system during an inspection, these measurements will be luminance measurements. In a low reflectivity mine, the "safety margin," where actual design levels exceeded 0.06 fL, will be reduced or nonexistent, thereby increasing the possibility of receiving a citation. Hence, keeping an STE-approved system clean is highly important.

It should be noted that the STE approval process is only concerned with the particular design requirements of the CFR. As noted previously these are only minimal standards and often it is desirable to exceed these light levels and consider additional factors when establishing a design. Specific examples include the desirability of providing greater light levels to raise the adaptation state of the eyes reducing contrast and glare problems from some luminaires, and the desirability of providing higher light levels on particular tasks (e.g., the coal face on continuous miners). In short, an STE-approved system should not be construed as an "optimally designed" system. These designs should be reviewed carefully; their performance in meeting visual needs carefully assessed. Guidelines for reviewing them are discussed in chapter 5.

In IC 9073, the relationship between luminance, L' (footlamberts), illumination, E (footcandles), and reflectivity, ρ, was given as $E = L'/\rho$.

Direct application of this relationship in the case of simulator-designed systems would create an unrealistic illumination design value because light output from luminaires will decrease with time because of reduction in lamp output (lumen depreciation, see chapter 3) and deterioration of the transmittance characteristics of the fixture lens. A more realistic result is obtained by modifying the formula with a light loss factor, Z: $E = L/P{\cdot}Z$. The accepted value for Z is 77 pct.

The modified formula is used to determine the required illumination design value, which is equivalent to a luminance of 0.06 fL when coal is assumed to be a perfectly diffuse reflector with a reflectance of 4 pct: $E = L/P{\cdot}Z$; $0.06/(0.04)(0.77)$ or 1.95, ≈ 2 fc.

STE APPLICATION PROCESS AND INFORMATION REQUIREMENTS

Any party, including mining companies, lighting hardware manufacturers, face equipment manufacturers, and consulting groups, may submit an illumination system design for an STE approval.

The following information must be submitted in such applications.

Application Form

One of two forms are available depending on whether the design is for longwalls or room-and-pillar face machines. The form identifies the basic application parameters of the design—machine type(s) and model(s), minimum- and maximum-entry dimensions. Other information is requested to facilitate processing of the application.

Machine Layout Drawing

The machine layout drawing (fig. 10) is used to present the spatial design of the lighting system. Dimensioned drawings of the machine to be lighted (typically plan and profile views) show location and orientation (and in some cases acceptable tolerances in location and orientation) of luminaires and shields. Notes on the application of diffusers must also be included. For longwalls the drawing must show the lighting system layout on the face supports, headgate, tailgate, and control station.

One-Line Diagram

The one-line diagram (fig. 11) is the basic document used for review of permissibility of the lighting system. The diagram represents the physical assembly of certified components used to construct the system, with one line used to show electrical interconnections between the components. Information requirements include (1) identification of all certified components used to construct the system, including explosion-proof numbers and numbers of certification reference drawings, if applicable; (2) specification of cable sizes and outside diameters; (3) specification of cable diameter range accepted by gland entrances to explosion-proof enclosures and switches; (4) notes relevant to special installation requirements necessary to maintain permissibility; and (5) delineation of permitted electrical configuration options and identification of optional equipment.

It is acceptable to standardize one-line diagrams for any particular luminaire-power supply combination. Once approved initially, the same one-line diagram may be submitted with future STE applications and need not be reapproved, saving significantly on approval time and costs. It is advisable that such diagrams be sufficiently generalized, yet comprehensive enough to include all possible alternative arrangements and optional equipment that might be utilized in an actual field installation.

Electrical Schematic

The electrical schematic, figure 12, is simply a wiring diagram utilized to detail interconnections between electrical components. The diagram need not detail the whole system but should include all representative parts and be adequate to show a purchaser of the system how to wire it.

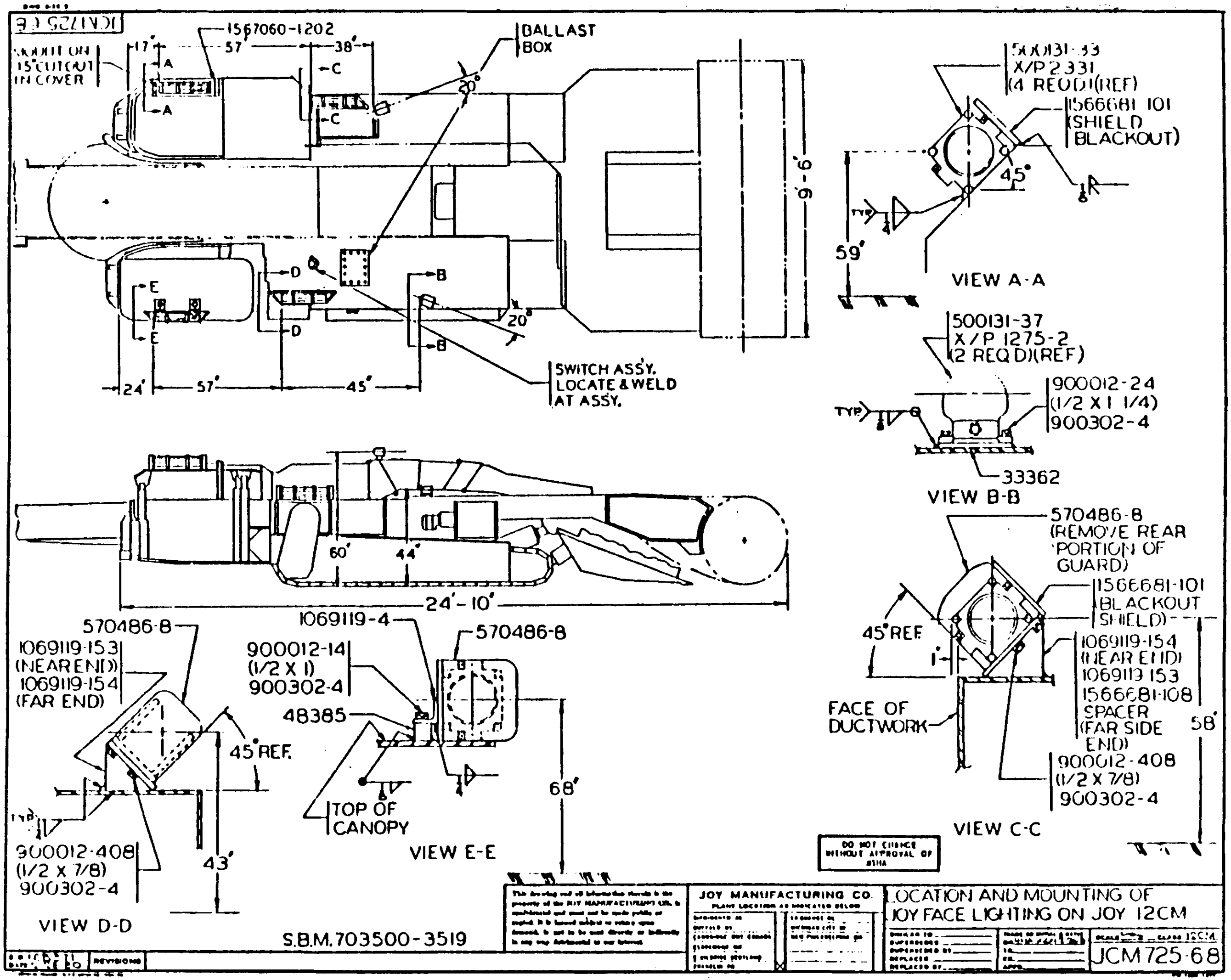


Figure 10.—System layout drawing.

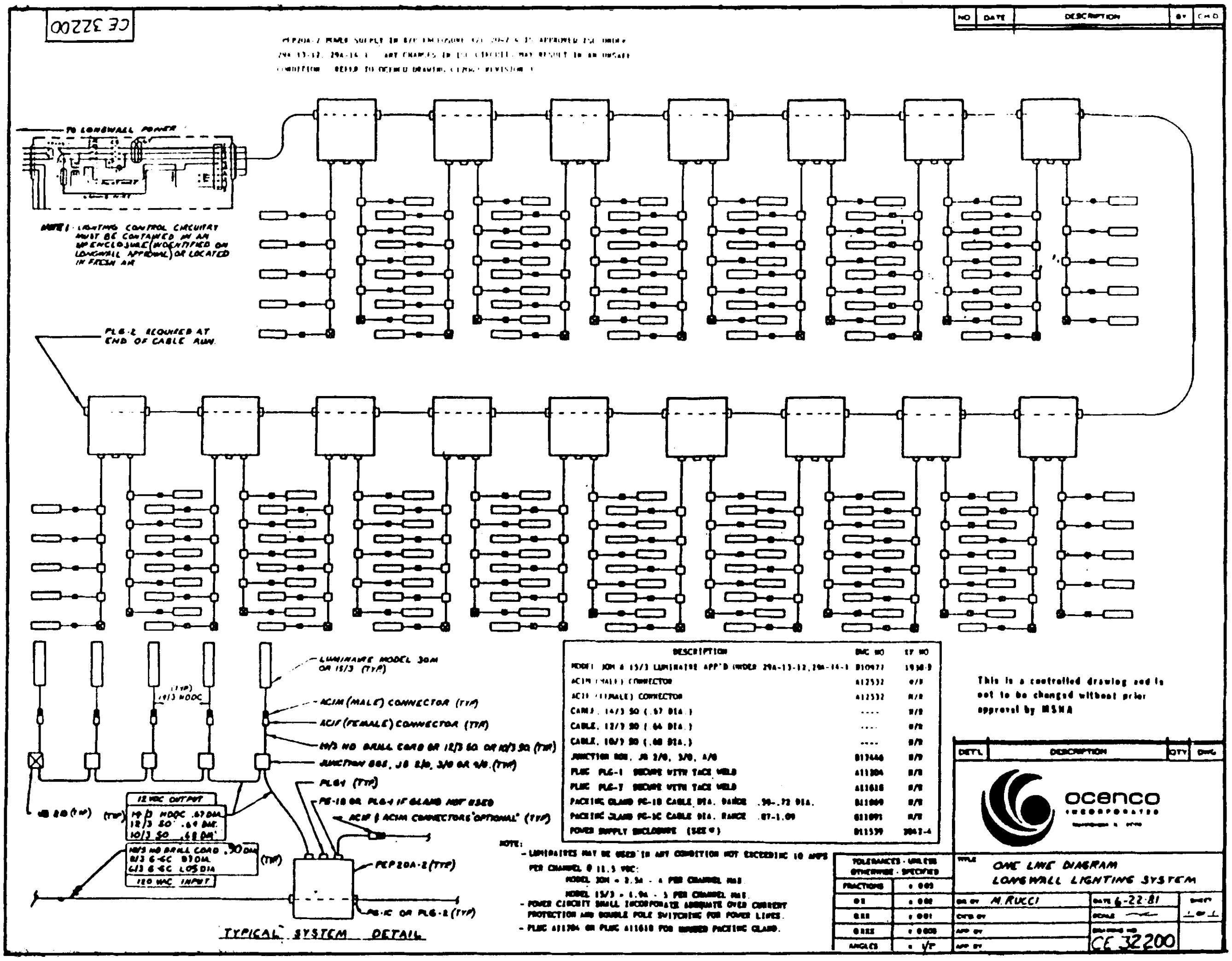


Figure 11.—One-line diagram.

On longwalls (and other stationary lighting systems) this drawing (or supplementary one, as required) should also show the systems incorporated to meet the special electrical requirements of stationary systems as discussed in the previous section (resistance-grounded-neutral, grounding circuit, required circuit-protective devices, pilot circuits, etc.).

Light Measurement Data

These data are used to verify that the system meets the light level requirements specified in the regulations, appendix A, for the particular machine type and seam height application. Incident light measurements must be taken for each 2- by 2-ft area on the surfaces surrounding the machine at the maximum entry dimensions for which the STE applies. Typically, they are reported on an "unfolded box" diagram, figure 13, where surfaces representing the roof, ribs, face, and floor are divided into 2- by 2-ft squares and indication is given simply whether incident light measured at these areas exceeds or is less than 2 fc.

These measurements must come from one of three sources:

1. Applicant's approved simulator (discussed at the end of this section).
2. Beckley (WV) Electrical Testing Center (BETL) simulator.—This simulator is available for use at a fee to interested parties. It is also used by BETL personnel to solve special lighting problems for mine operators. A subsequent section discusses this service in more detail.
3. Field data.—Field measurements at the mine site by BETL personnel can be utilized in establishing an STE. These are obtained upon mine operator request. A fee is charged for obtaining them and this practice would be dependent on availability of BETL personnel.

All longwall STE approvals require an on-site inspection by BETL representatives to verify light level compliance and installation details as specified in the STE application. These are conducted at the applicant's expense. Luminaires must be installed in accordance with the machine layout drawing at the headgate, control station, and a representative area of the face and travelway. The tailgate is usually not required to be lighted for this inspection (getting power to the tail would be difficult for a partial installation) but accurate tailgate drawings and simulator light measurements must be submitted with the STE application. If those drawings are found inaccurate upon field inspection, an additional field inspection might be required, at the applicant's expense, to inspect installed

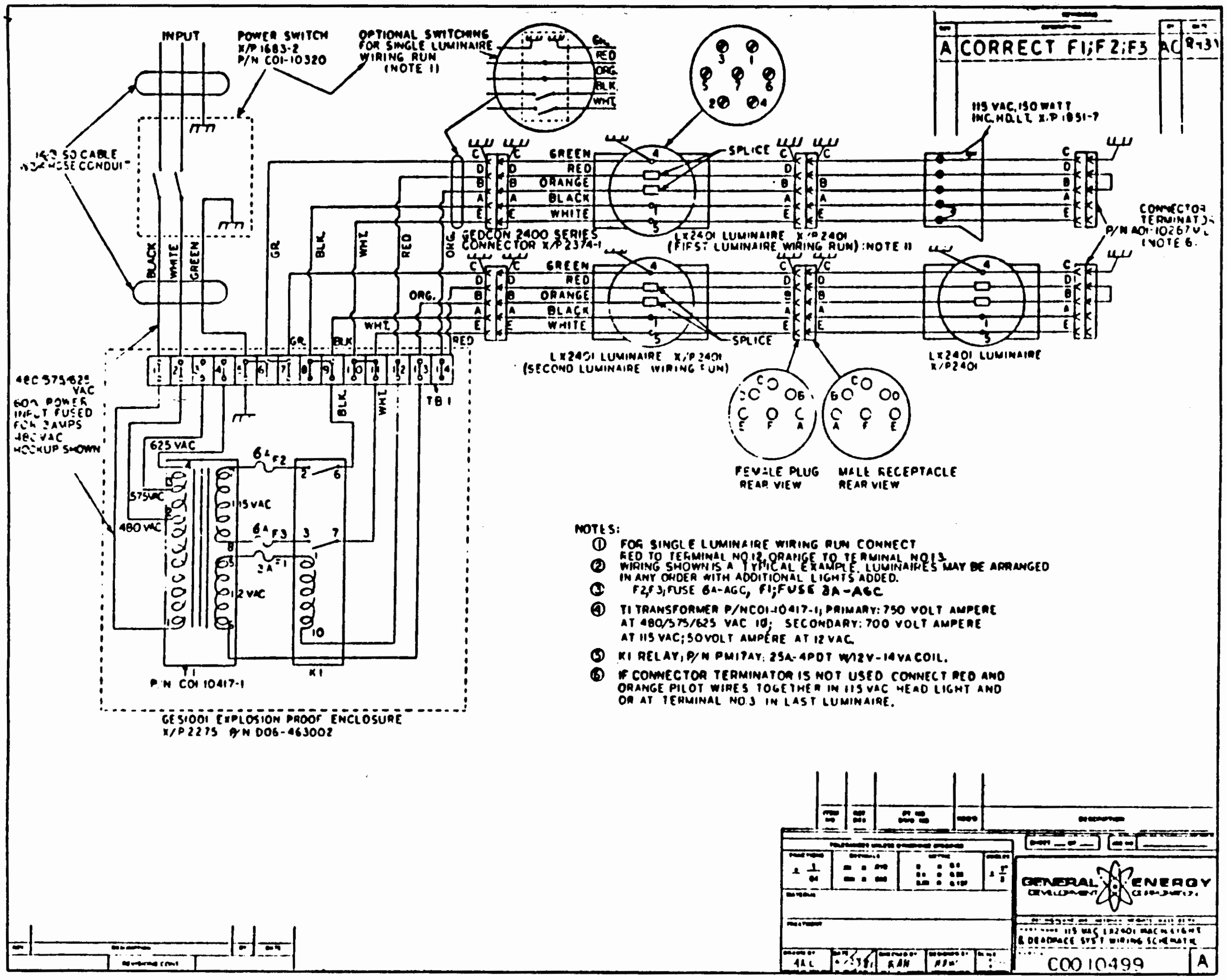


Figure 12.—Electrical schematic diagram.

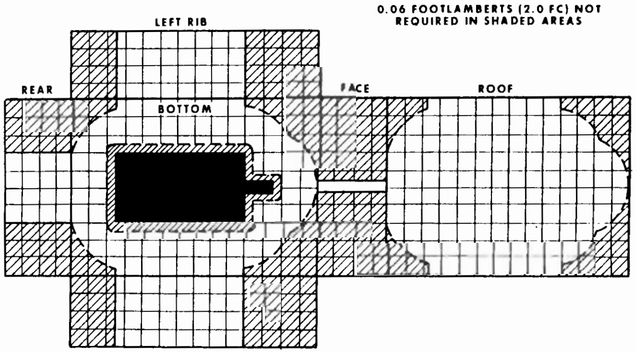


Figure 13.—"Unfolded-box" diagram for presenting light measurement data.

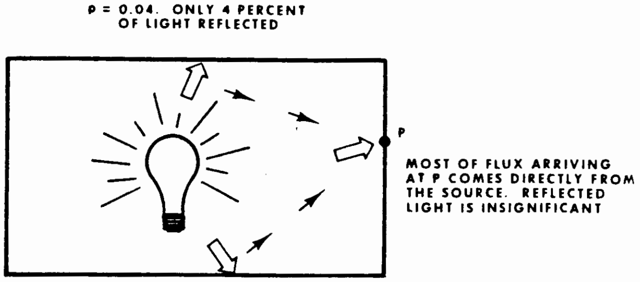


Figure 14.—Significance of interreflections when taking light measurements in mine simulators.

tailgate-area lighting. These light measurements are necessary in addition to simulator values because of the many sources of shadows on actual faces, which cannot be accurately simulated.

It has often been the case that mine operators have filed for an STE for a longwall lighting system after the system was installed and operating. In such event it would be to the operator's advantage to file for the STE promptly. This would insure that the on-site light measurements are least affected by the various time-related factors that tend to reduce system light output.

Construction of an environment to accurately simulate a mine for lighting design purposes is relatively simple because of the low reflectivity of the mine environment. Figure 14 illustrates a light source in a mine entry.

If the reflectivity of the perimeter walls was high, significant amounts of the light arriving at P would have been reflected from the other surfaces. However since coal mine reflectivities are low, averaging only 4 pct, light coming directly from the source comprises nearly all of the light reaching P; interreflections are negligible. This means accurate incident measurements can be made without locating actual walls of similar reflectivity to coal to simulate the entry perimeters; rather, it is only necessary to take incident reading at the points that define the wall. The only requisites for a simulator that would be capable of simulating any size entry are (1) its dimensions exceed the maximum size of entry to be simulated and (2) all walls must be painted with low reflectivity paint.

Specific MSHA requirements for construction and use of simulators follow:

1. The building should exclude exterior light such that measurements, with an artificial light source in the simulator turned off, are less than 0.1 fc at any point.
2. The walls, floor, and ceiling must have a reflectivity less than 5 pct. This is achievable with most commercial flat-black paints. To assist the operator of the simulator in confirming this, MSHA will measure the reflectance of a sample of the selected paint on the materials used to construct the walls of the simulator.
3. Cosine and color corrected incident photometers (see chapter 1), calibrated to standards traceable to the National Bureau of Standards, must be used to take light measurements. BETL offers such calibration at a fee for any party operating an approved simulator.
4. A gridwork should be established on the floor and at the perimeter planes that define the entry roof, ribs, and face such that these planes are divided into 2- by 2-ft square fields. Incident light measurements are made at all intersecting lines on this gridwork. In many simulators, such a gridwork is established by suspending wires 2 ft apart in a given plane and locating a marker every 2 ft along the wire. The photometer head may be angled to the light source for maximum reading. Light measurements on the floor begin 1 ft from the machine perimeter.
5. Room temperature should be monitored and recorded when measurements are made because temperature can affect photometer calibration and light output of fluorescent lamps.
6. MSHA will initially inspect the facility and observe techniques used to take light measurements. This inspection may be repeated at any future date.

Short Circuit Calculations (Longwall-Stationary Systems)

Using the procedure detailed previously "short-circuit" calculations must be submitted to determine maximum allowable breaker settings. To do this, it is necessary to (1) determine the current path of the system to the termination that yields highest resistive value, (2) specify cable diameters and lengths accordingly, and (3) specify type and tolerance factor of the system circuit breaker. The BETL field inspector of the lighting system will also require a demonstration of the operativeness of the circuit breaker upon field inspection of the lighting system.

SPECIFYING OPTIONAL EQUIPMENT ON STE APPLICATIONS

As noted previously, systems may be specified in applications for STE approval so that they include various equipment or configuration options. To simplify paperwork requirements for end users of the design, it is desirable that useful options be specified in the one-line drawing. In the STE approval process, review of the optional components would be limited to determining (1) the permissibility of the components or system, and (2) that additional luminaires do not create objectionable glare for the machine operators.

The following illustrate desirable options to specify on STE applications:

1. Additional headlights might be specified as an option on continuous miners and other face machines since many operators prefer having higher light levels on the face.
2. Adjustable headlights are desirable on face drills to supplement face lighting on drill hole positions (MSHA will not consider adjustable headlights in meeting the Federal standard, hence all such lights are "supplementary").
3. Permissible connectors are desirable in many applications.

MSHA REVIEW OF STE APPLICATIONS

STE applications are submitted to BETL, a division of A&CC located at the MSHA Academy in Beckley, WV. The following procedure is used in reviewing the application.

1. The one-line diagram is forwarded to the Division of Electrical Safety, another subdivision of A&CC in Triadelphia, WV, for review of the permissibility of the proposed system in accordance with the system requirements contained or referenced in part 26 of the CFR. If the one-line diagram has been previously approved, this is verified by BETL and the diagram is not resubmitted to the Division of Electrical Safety. Total system approval times are reduced from an average of 3 weeks to 1 week for applications with previously approved one-line diagrams.
2. BETL reviews the light measurement data to see if the system as depicted in the machine layout drawings is in compliance with the illumination standards that apply to the particular application. This review may or may not require mocking up the machine in the BETL simulator and taking measurements. The "reasonableness" of the measurements based on BETL experience with similar design has bearing on whether the machine is simulated at BETL. If the measurements are found in error, BETL may request a visit to the applicant's simulator to inspect the facility and review measurement procedures. All longwall applications require an on-site inspection with the system installed as specified in the drawing on representative areas of the face to verify compliance of the light measurements.
3. BETL reviews the machine-layout drawing and specifications of shields and diffusers to determine whether the design causes excessive discomfort glare. This evaluation may require resimulation of the design in the BETL

laboratory. This evaluation, although subjective, is based upon extensive experience of BETL personnel relative to the acceptability of lighting systems in the field. Operator's stations are evaluated with the greatest scrutiny. If the system is deemed to cause excessive glare, BETL will suggest changes to correct the problem.

4. BETL reviews electrical schematic and short-circuit calculations (longwall only) for (1) verification that the electrical design complies with the requirements of CFR 75.1719-2 and (2) adequate depiction of how the system is wired.

Upon a favorable MSHA review of these four aspects, the applicant is awarded an STE approval identified by an approval number.

MODIFICATION OF STE-APPROVED DESIGNS

It has proven necessary to establish procedures for the modification of STE-approved lighting designs to accommodate the varying conditions of application that exist in the field. For example, actual machine geometry may vary from the STE geometry because of optional equipment, modifications, and variances in how the machine was built; fixtures may be located in the STE design where they are exposed to excessive mechanical hazard, lack anchor points for mounting, prevent machine servicing, or cause glare; or, in the case of longwalls, equipment configuration changes might occur between successive panels.

Two procedures can be used for modifying STE designs—field modification and STE extension. Table 3 explains and compares these two alternatives. As noted in the table, under both procedures any change is permitted that does not affect machine permissibility or light level compliance. This includes addition of shields and diffusers, changes in luminaire locations, and changes in size or number of luminaires.

As implied in the table, there are significant limitations in the application of a field-modified STE whereas designs that incorporate STE extensions may be applied the same as an STE design. Because of this important advantage and the availability of BETL and most lighting hardware manufacturers to assist operators in obtaining an STE extension, this is the recommended route for modifying an STE design in nearly all cases. A discussion of BETL as a resource in helping mine operators to solve lighting problems and the outline of a procedure operators may take to obtain an STE extension are presented at the end of this section.

A common design modification sought by operators is to substitute one manufacturer's headlight for another. Photometrically (i.e., in terms of light output and distribution), there is approximate equivalence among most 70-W high pressure sodium, 100-W mercury vapor, and 150-W incandescent fixtures. BETL permits substitutions within the listing in table 4 and it is unnecessary to provide light measurements for such substitution in any application for an STE extension. It is necessary, however, to provide a new one-line diagram showing the substituted headlight.

Because of frequent equipment changes on longwalls, especially between panels, there may be some question of the effect on the status of the STE approval. The STE, in general, is tied with the face supports and travels with them from section to section and mine to mine, so long as the application of the supports is within the seam height range specified in the STE. Most equipment changes can be covered by an STE extension. Examples where an extension would be required to maintain the status of the approval include—

Change in panline;
Change in shearer or plow;
Change in control unit; and
Any change that modifies the configuration of the head or tail areas such as new crusher, new conveyor drives,

Table 3.—Comparison of field modifications of STE's and STE extensions

	Field modification	STE extension
Modifications permitted	Any change(s) that do not affect permissibility of the machine and maintain illumination levels required for machine application.	Same as field modification.
Process for obtaining approval	Application made by user (mine operator) to local MSHA district manager. Electrical inspector visits mine and (1) verifies light level compliance by taking luminance measurements with special go, no-go photometer,[1] and (2) checks permissibility of the machine.	Application by STE approval holder (with exception of longwalls, typically a lighting hardware manufacturer) to BETL, submitting modified machine layout drawing, 1-line diagram, etc., as appropriate. Light measurements may be taken in a simulator or at the mine site (by BETL representative). Cooperation of BETL and most lighting manufacturers enables the mine operator to initiate an effort to obtain an STE extension even if he or she is not the approval holder.
Important aspects of resultant approval.	Maximum entry dimensions for which the STE approval applies are—height, height where measurements taken plus 12 in; width, width where measurements taken plus 24 in. Applies to all similar machines in same mine when (a) they have the same STE number and (b) identical modifications are made to each machine. However, does not apply to other mines.	Maximum entry dimensions for which the approval applies are independent of any particular mine site and represent the maximum capability of the system. Approval applies to application of the modified design in any mine. This is helpful to multimine companies and other companies having the same problem.

[1] The reflected light (luminance) measuring instrument used by MSHA inspectors when it is necessary to field-inspect lighting systems. In this case, the instrument is calibrated to give a favorable signal (i.e., system complies) at an illumination level of 0.05 fL.

Table 4.—Headlight equivalence listing[1]

(Explosion-proof approved for 100-W mercury vapor, 70-W sodium, and 150-W incandescent fixtures)

Manufacturer	Model or part	Certificate number	Manufacturer	Model or part	Certificate number
Control Products	2002, 2003, 2004	X/P 1468-28	Joy	571390-10000	X/P 1275-1
Crouse-Hinds	MHL1B	X/P 2301-1	McJunkin	2000	X/P 2145-5
Guyan	5234	X/P 984-4	Mining Controls	20043	X/P 2372
Huntington Brass	380, 381, 382	X/P 1774-2	Mosebach	FL38150SPX10	X/P 1851-4, 5
	700	X/P 2659-0	Ocenco	HE-100X	X/P 2320

[1] An extension can be obtained to substitute between any 2 headlights on this list without light measurements, including substituting mercury vapor for sodium, etc.

different supports in this vicinity, new transfer point arrangement.

Changes in seam height and number of supports such that the limits specified in the STE are exceeded would also require an extension. Foresight should be used to originally specify ranges to cover future application of the longwall equipment.

In addition to conducting technical review of lighting system designs, BETL is available to help mine operators resolve problems they have encountered in implementing mine-lighting systems. The following are some of the services BETL can provide at no cost to the operator.

1. Assisting the mine operator in establishing appropriate design modifications and obtaining STE extensions to resolve various problems.
2. Reviewing hardware alternatives with the operator for a particular application.
3. Identifying, for the operator's review, currently available STE's for a particular machine model and seam height.
4. Verifying calibration of mine operators go, no-go photometers (recalibration, if necessary, would be the operator's responsibility).
5. Establishing new lighting designs for difficult applications.
6. Assisting mine operators and independent machine shops in making design modifications, including integration into the machine, when installing lighting systems during equipment rebuild.

For example, say, at a given mine, all the bolter operators on a particular model machine are experiencing a glare problem with a particular luminaire (it is preferable that reported glare problems are consistent among the various machine operators). The mine could contact BETL and explain the problem. BETL would send representatives to the mine and, in conjunction with mine personnel, modifications would be established to resolve the problem. After the modification has proven successful, BETL would then contact the lighting manufacturer to develop revised machine-layout and one-line drawings (one-line drawings only required if the electrical components are changed) or have the mine operator develop them. The revised layouts and drawings would then be submitted to BETL in an extension application.

It should be emphasized that visiting BETL representatives have neither the intent nor authority to issue citations for lighting violations. Mine operators are urged to take advantage of this valuable resource. Contacting BETL is a good first step when any significant lighting problem is being experienced.

REQUIREMENTS FOR INSTALLATION OF LIGHTING SYSTEMS

All mobile-face machines and longwalls have a "total" machine or system approval for use in coal mines. The addition and electrical integration of a lighting system is viewed as a modification of the total machine design, which could potentially void the machine approval. Hence, a *field modification* must be applied for by the mine operator on a machine-by-machine basis before installing a lighting system, regardless of whether the lighting system does or does not have an STE approval. With STE-approved systems, required documentation for a field modification is simply the one-line diagram of the STE with any additional information denoted to show exactly how the lighting system will be electrically integrated into the particular machine in question (e.g., switches, fusing, entrance glands). For non-STE-approved systems, the operators would be required to make their own equivalent drawings.

Before installing the STE-approved system, mine operators should confirm that external machine geometry and dimensions agree with the machine depicted in the STE layout drawing. If any deviations exist that alter the light distribution of the system (e.g., machine is equipped with certain options or it has been modified), the STE would not apply and an STE extension would have to be obtained.

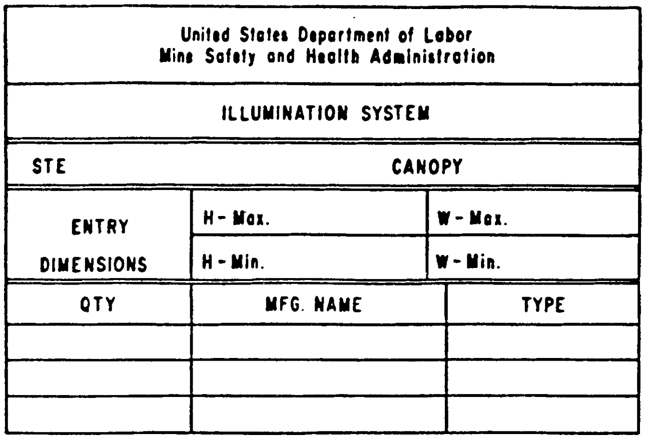
Luminaires, diffusers, and shields must be installed as specified on the machine layout drawing. The following tolerances are permitted by MSHA in locating or orienting luminaires: Fluorescent luminaires, ±12 in; high-pressure sodium luminaires, ±12 in; incandescent luminaires, ±6 in; and headlights, ±5°.

Problems in meeting these requirements, for example, inadequate anchor points for mounting the luminaire, the fixture is specified to be installed in undesirable locations such as on an explosion-proof enclosure or frequently removed coverpan, etc., may be encountered. In such event the operator should consider modifying the lighting system design through the STE-extension process.

For STE-approved systems, a metal plate containing pertinent information about the STE (see figure 15) is required to be attached to the machine near the machine permissibility plate. This plate is generally furnished by the lighting hardware suppliers.

INSPECTION OF FACE LIGHTING SYSTEMS

Field inspection of lighting systems involves checking that (1) the permissibility of the lighting system is being maintained and (2) the system is meeting the applicable



United States Department of Labor
Mine Safety and Health Administration

ILLUMINATION SYSTEM

STE CANOPY

ENTRY	H - Max.	W - Max.
DIMENSIONS	H - Min.	W - Min.

QTY	MFG. NAME	TYPE

Figure 15.—STE system approval plate.

Federal lighting standards. Permissibility checks are made in accordance with criteria discussed in chapter 6, "Installing and Maintaining Mine Lighting Systems." Procedures for verifying compliance with the lighting standards vary for STE- and non-STE-approved lighting systems.

Procedures for STE-Approved Systems

As noted previously, an STE guarantees the mine operator compliance with the lighting standards as long as the approved design and application specifications are being met in the actual installation. Under these circumstances inspectors can not take light measurements. The review will simply consist of the following:

1. Verification that the lighting fixtures are properly located and oriented as specified in the STE machine layout drawing.
2. Verification that all lighting fixtures are operating properly.
3. A check to see that excessive coal dust, dirt, or other material is not present on the luminaires and light transmission is not being blocked by any nonspecified means.
4. A check to see that entry dimensions are within the limits specified in the STE.
5. Verification that the system is being operated in compliance with other requirements specified in the STE. For example, if use of a ventilation curtain at the headgate or tailgate area of a longwall has affected the design of the lighting system in that area, such a curtain must actually be in place when inspected, or light measurements may be taken.

Mine operators should keep the STE cover page and machine-layout drawing(s) on file at the mine for this inspection.

If the actual installation fails to meet one or more of these specifications, this alone does not permit issuance of a citation. Rather, light measurements must be made to establish that the system is not meeting required light levels. (This is necessary because compliance with an STE itself is not a requirement but just a means for meeting the Federal lighting standards.) Instruments and techniques used in taking these measurements are discussed later in this section.

Procedures for non-STE-Approved Systems

Light measurements are necessary for verification that non-STE-approved systems are in compliance with the lighting standards. These will be taken upon the initial inspection and may be repeated upon any future inspection at the inspector's discretion. In general they will not be repeated unless improper maintenance, changes in layout, or changes in entry dimensions imply that the light levels provided by the system might be reduced.

Instruments and Techniques for Taking Light Measurements

The go, no-go photometer, discussed in chapter 1, is the only instrument permitted to be used in taking light measurements for inspection purposes. The instrument has no numerical scale; it emits a green light when the measured luminance exceeds or is equal to 0.06 fL and a red light when measured luminance is less than 0.06 fL.

The machine to be measured should be positioned in a nonrockdusted entry. Positioning requirements vary for each machine depending on the lighting standards that apply to that machine. Appendix A describes these requirements for each particular category. In general, positioning requires (1) centering the machine if the requirement is that the entire entry must be lighted, or (2) locating ribs or face at the edge of the lighting perimeter if the requirement is that the standard must be met only within a certain distance of the machine.

Compliance with the 0.06-fL standard is determined by measuring the average luminance of each square or circular field, 3 to 5 ft^2 in area, on the surfaces required to be lighted. The go, no-go photometer yields the average luminance of any surface subtending the 27° solid viewing angle through which the instrument's lens accepts light. Thus, the procedure used to take measurements for compliance verification is to hold the meter perpendicular to the surface to be measured at a distance between 4 and 5 ft from that surface (fig. 16).

When clearance does not permit the meter to be held at this range, the procedure is revised as follows:

1. Divide the surface in question into 2- by 2-ft square fields.
2. At each corner of each square field, hold the go, no-go photometer perpendicular to the surface at a 2-ft distance from the surface. The instrument will be measuring the average luminance over an area of 100 in^2 (see figure 17).
3. If one or more of the four readings in the 2- by 2-ft field yields a green light, the field is assumed to be in compliance. Only if all four readings yield a red light is the field deemed not in compliance (see figure 17).

Measurements should not be taken on areas where shadows are cast by manually set jacks or timbers or by ventilation curtains.

For STE-approved systems, light measurements should be taken utilizing the techniques discussed only at the surfaces illuminated by luminaire(s) that are improperly maintained or fail to comply with the specifications of the STE. In doing so, the inspector will visually examine the affected area and take measurements at the "darkest spot" apparent from such examination.

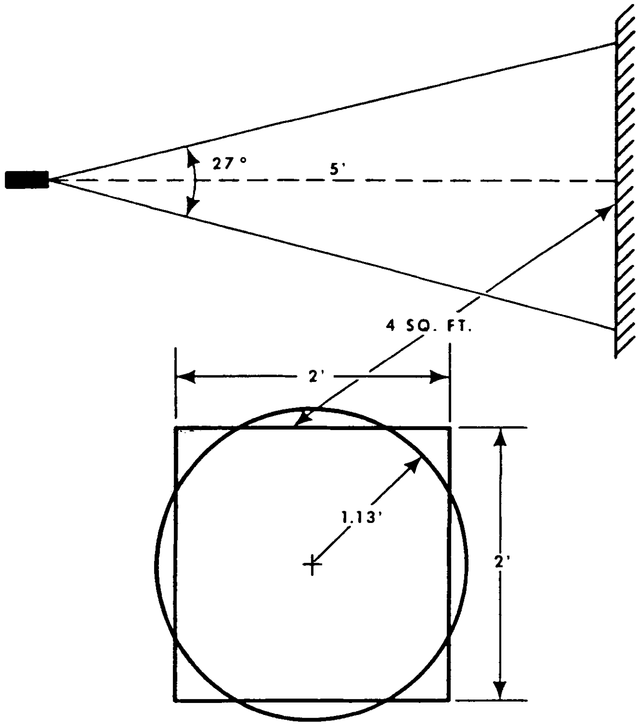


Figure 16.—Procedure for using go, no-go photometer when clearance permits holding the meter 5 ft from entry walls.

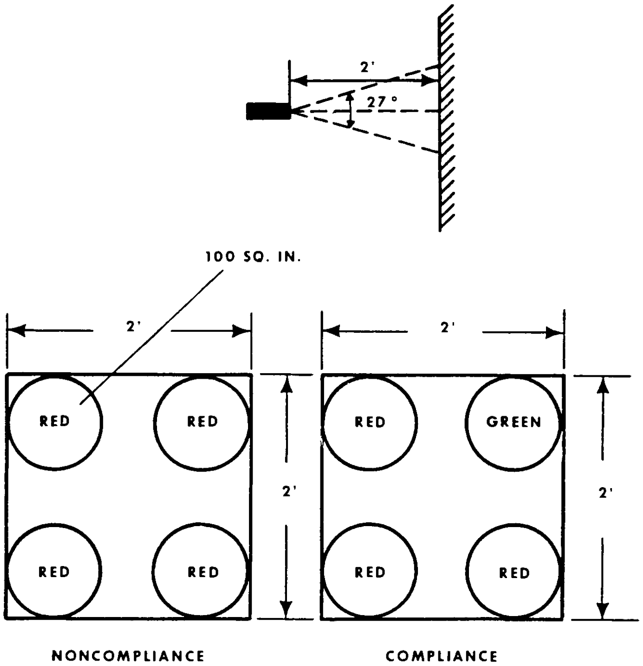


Figure 17.—Procedure for using go, no-go photometer when clearance does not permit holding meter 5 ft from entry walls.

For non-STE-approved systems, measurements may be taken at any surface required to be illuminated. Typically the inspector will visually examine surfaces and take measurements, utilizing the previously described techniques, at the "dim" spots.

Additional Requirements To Improve Visibility Underground

As noted in IC 9073 (chapter 3), the provision of artificial illumination is not the only means to improve the visibility of objects and details underground; reflectivity and contrast characteristics of the environment itself may be altered to achieve improved visibility. In recognition of this, the following provisions are required in underground mining:

1. The paint utilized on all exterior surfaces of face machines must have a reflectance of at least 30 pct except on surfaces where highly reflective paint would adversely affect visibility. The major exception is the interior of cab surfaces where high reflected light levels from cap lamp and/or interior-mounted luminaires would cause excessive contrast that could be detrimental to visibility between the cab interior and the darker surroundings the machine operator is observing.
2. If area lighting systems are used in the vicinity of self-propelled face machine instead of machine-mounted systems, reflectors must be used to make the machines more visible (the luminaires would serve this purpose on machine-mounted systems. The reflectors must be at least 10 in^2 in surface area. One is required at the outby end of continuous miners and loaders and both the inby and outby ends of all other face machines.
3. Six square inches of reflective tape or equivalent reflective material are required on the front, both sides, and back of miners' hardhats.

CHAPTER 3.—LAMPS AND BALLASTS

Lamps and ballasts are the basic building blocks of lighting hardware and systems. This chapter addresses the lamps and ballastry utilized in U.S. underground coal mine application, explaining their functional and performance characteristics, particularly as they are relevant to mining application. This information is an important basis for success in hardware selection and system design, implementation, and maintenance.

CRITERIA FOR LAMP PERFORMANCE CHARACTERIZATION

The following is a list of performance criteria commonly used to characterize performance of lamps and their associated circuitry.

Spectral Energy Distribution.—As discussed in IC 9073 (chapter 2), light sources broadcast their energy at different wavelengths, and this affects the perception of both color and brightness. A spectral energy distribution curve shows the relative amounts of the total electromagnetic radiation emitted by a source at each wavelength within the visible range of the spectrum. In mining application, this information is useful as a basis for judging (1) the color rendering ability of a lamp, which may be important in the performance of certain tasks such as blast and electrical wiring, perception of color-coded signs, etc.; and (2) the efficiency of the source under circumstances of low background illumination (scotopic vision) where "green" wavelength light is more readily perceived. Spectral energy distribution curves, which show energy emission beyond the visible portion of the spectrum, are useful in evaluating heat (infrared) and ultraviolet radiation production of the lamp.

Efficacy.—Efficacy is a measure of the efficiency of a lamp in converting electrical energy into visible light energy. In strict terms, efficacy cannot be equated to efficiency. The efficiency of an energy converting device is a ratio of input power to useful output power, expressed as a percentage. For example, an electric motor consuming 100 kW of electrical power might deliver 75 kW of mechanical power to the drive shaft it turns and is said to exhibit 75 pct efficiency. However, as noted in IC 9073 (chapter 2), all light energy is not perceived equally by the eye. A human weighting function must be considered to account for the varying perception of brightness dependent on the wavelength of light. This is taken into account in the measure of light energy and its expression in terms of the lumen. Hence, a related measure, efficacy, is used to measure the efficiency of light sources and is presented in terms of lumens output per watt input or lumen per watt. As noted in IC 9073, the most efficient light sources in producing a perception of brightness would emit all light energy at the wavelength of greatest sensitivity—555 nm. If a lamp could convert 100 pct of its power to 555-nm wavelength light, it would have an efficacy of 680 lm/W. In most cases, however, a more balanced distribution is desirable. If a source has a spectral distribution curve that parallels the spectral luminous efficiency curve (IC 9073, chapter 2), the maximum efficacy of that lamp would be about 200 lm/W. Some available lamps approach this efficacy but have some problems in wavelength balance. In mine lighting, efficacy is important with respect to the following:

1. Assessing power requirements and costs of alternative systems. Systems using high efficacy lamps will have lower power requirements and costs than ones using low efficacy lamps. Note that published efficacy value usually does not consider wattage consumption of associated circuitry (transformers, resistors, line losses, ballasts). These must be added for a complete power assessment.
2. Evaluating suitability of the lamp in meeting light output requirements for a particular application. Many mine applications require high light levels, while at the same time, it is desirable to minimize the number of fixtures. Lamps with higher efficacy are generally better able to meet this need without producing an excessive level of heat (an important consideration in coal mining luminaire design).

Lumen Depreciation-Mean Lumens.—The amount of light energy emitted by a lamp diminishes significantly (up to 33 pct) over the course of its service life. Depending on the type of lamp, output reduction is caused by different mechanisms, which have an effect even in the mildest operating environments. Lumen depreciation is usually given as the ratio of lumen output at the end of lamp life to the initial lumen output. Lamp wattage consumption also decreases over time, but not as fast as lumen depreciation; hence, there is also some efficacy depreciation over lamp life. In general, the percentage of efficacy decline is less than the percentage of lumen depreciation. Note that lumen depreciation accounts only for light loss from the lamp. This will usually be less than light loss from the luminaire due to deterioration and dust and dirt accumulation over time, which also contribute to diminished light output. Lumen depreciation is an important consideration in system design for mining application, especially when developing designs in simulators. In many applications, premature lamp failure and difficult housekeeping circumstances complicate quantitative consideration of lumen depreciation. Mean lumens, the average lumen output of the lamp throughout its rated life, is the most meaningful quantity to consider for design purposes.

Lamp Mortality-Rated Lamp Service Life.—Degradation of lamp operational parts during the course of lamp service life eventually results in failure. In lamp design, the question of economics is always considered jointly with lamp service life. Some lamp designs could be modified to increase service life, but this would result in efficacy reductions that could increase operating costs to the point that the lamps would be uneconomical for most applications. All lamps, of course, do not realize equal life. Rated lamp service life is a statistical quantity defined as the life achieved by the median lamp of a large group of lamps burned under controlled conditions. Fifty percent of lamps will have failed by the time rated service life is reached, and 50 pct will remain operational. A plot of lamp failures versus time is called a lamp mortality curve (fig. 18). Control parameters in development of these statistics are the burn cycle (length of time the lamp is burned before shutting off and restarting) and the input voltage (maintained at design specification). Mercury vapor lamps are an exception. These lamps have extremely long life, and efficacy drops to a point where it is considered uneconomical

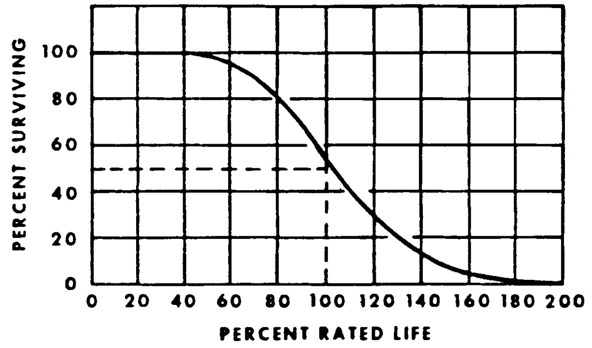


Figure 18.—Lamp mortality curve example.

to continue burning after only one-third of the lamps have failed. Hence, published mercury vapor lamp values life values are at the 33-pct-failed point.

In mining application, laboratory-based measurements of lamp life will frequently be irrelevant because of the harsh operating circumstances of this application. Lamp suppliers may present generalizations on lamp economics which are relevant to most applications, but do not apply to the underground coal mine. Therefore, the problem should not be ignored. Evidence shows that total lamp-associated costs can be very high in mining applications. Site performance data should be collected as a basis for guiding appropriate decisionmaking to reduce these costs. In this regard, procedures for evaluating, and subsequently reducing lamp-associated costs, are presented in chapter 6.

Lamp Shapes.—Lamps are available in different shapes which, in conjunction with lamp dimensions, are important with respect to luminaire configuration and light control. Figure 19 shows the more common lamp shapes and corresponding abbreviations. Light center length is an important dimension for some lamp types when they are used in conjunction with reflectors.

INCANDESCENT LAMPS

Principle of Operation

As described in IC 9073 (chapter 2), any material heated to a high temperature will emit electromagnetic radiation. For example, a horseshoe glows in the blacksmith's hearth. This process of light production is called incandescence and is the principle involved in operation of an incandescent lamp. Basically, an incandescent lamp (fig. 20) consists of a small-diameter tungsten wire called a filament, supported in an inert environment to prevent oxidation. An electrical potential (voltage) is placed across the filament, and current is passed through it, generating heat because of the filament's electrical resistance. Filament temperature rises to a high steady-state value and the filament emits electromagnetic radiation in the ultraviolet, visible, and infrared portion of the spectrum. Tungsten is the material of choice in construction of the filament because of its ductility, desirable emission characteristics (because of its high melting temperature), and its reasonable strength and relatively slow evaporation at high temperature. Evaporation, however, eventually does take its toll and causes a break in tungsten filament continuity, ending useful incandescent lamp life.

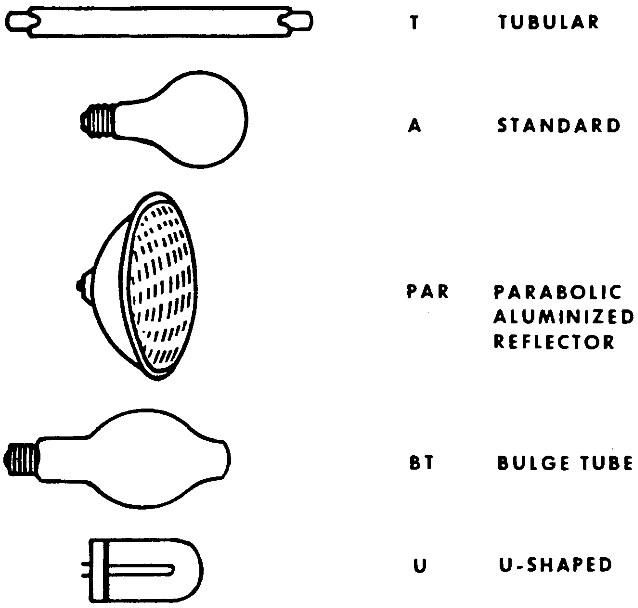


Figure 19.—Common shapes of mine lamps and letter designations.

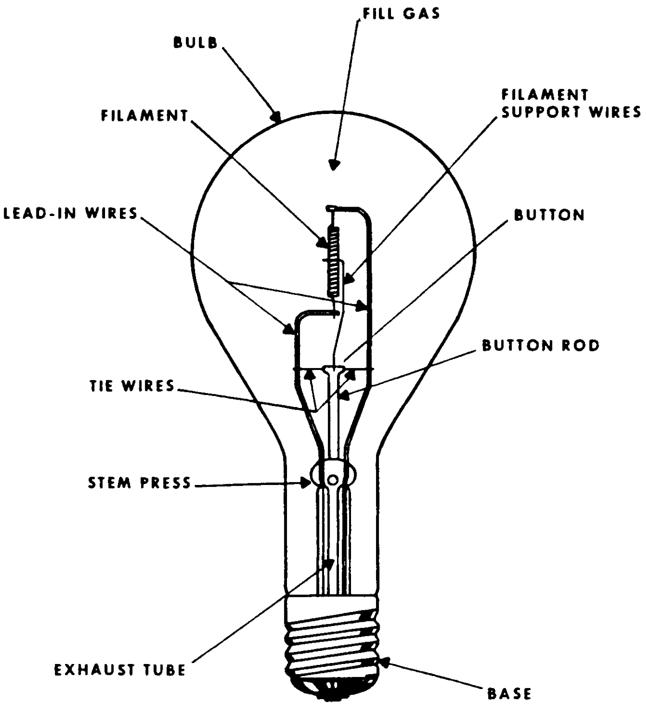


Figure 20.—Construction of typical incandescent lamp.

Life-Efficacy Relationship

As noted, an incandescent body produces electromagnetic radiation across a broad portion of the electromagnetic spectrum (see figure 21). Light source efficiency requires that as high a portion of this radiation as possible be in the visible portion of the spectrum. This is achieved by increasing the temperature of the body. Increased temperature, however, increases the rate of material

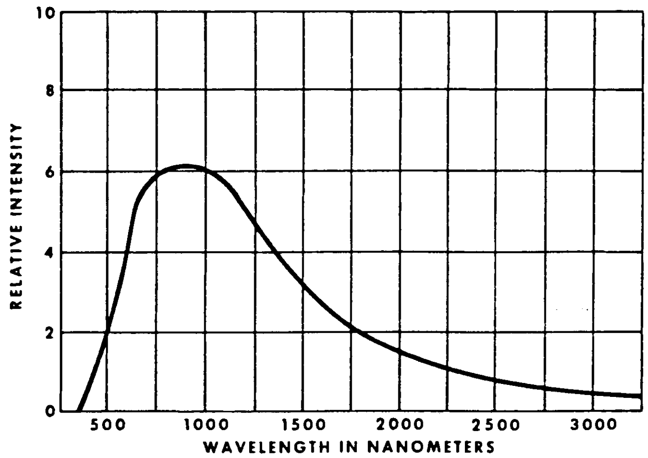


Figure 21.—Spectral energy distribution of tungsten at 3,000 K.

evaporation, reducing the life of the lamp. Hence, the key of incandescent lamp design is achieving an optimum balance between life and efficacy. In this regard, the following important design aspects are noted:

1. *Filament Electrical Character.*—A filament can essentially be viewed as a resistor. Physically, its resistance is increased by increasing its length or decreasing its diameter. Power consumption follows Ohm's law ($P = IE = E^2/R$). For equal voltage lamps, filament resistance will decrease (shorter and/or larger diameter filaments), as lamp wattage increases. For equal wattage lamps, filament resistance will increase (smaller diameter and/or longer filaments), as voltage increases.

2. *Filament Heat Dissipation Character.*—Heat dissipation from a lamp is undesirable because it indicates input power is being converted to heat rather than useful light. Dissipation is proportional to the surface area of the filament. For equal wattage lamps, filaments will have smaller surface areas for low-voltage lamps than for high-voltage lamps. For equal voltage lamps, high-wattage lamps will have smaller surface area filaments than low-wattage lamps. This implies that greater efficacy is achievable on low-voltage and on high-wattage lamps. For example, a 150-W, 120-V lamp produces about 34 pct more light than three 50-W, 120-V lamps. Note also that low-voltage, high-wattage lamps have greater diameter filaments, which improves their mechanical strength. These lamps are frequently applied in mining application.

3. *Filament Evaporation-Fill Gas.*—Filaments must be operated in an inert atmosphere to prevent oxidation. Originally they were operated in a vacuum. However, it was found that introduction of inert gases (nitrogen, argon, krypton) reduced filament evaporation. This enables operating at higher temperatures, improves efficacy, and improves service life. Heat losses from convection, however, must also be contended with. Heavy molecular weight gases (e.g., krypton) are better than light molecular weight gases (e.g., argon) because convective losses are less. Expense prevents wholesale application of heavy gases. Miners' cap lamps are an exception and are krypton-filled to minimize battery drain. Note that for low-wattage lamps (in the case of 120-V lamps, those 40 W or less) with relatively high surface area filaments, convective heat losses are very high. Introduction of inert gases shows no advantage for these lamps and they are operated in vacuum.

4. *Filament Shape and Supports.*—Filaments can be made in various forms. The wire may be straight or wound in coiled and coiled-coil fashion. The coiled and, to an even greater degree, the coiled-coil configurations improve efficacy by reducing convective heat losses. They also contribute to the mechanical strength of the filament. Filaments are supported in various configurations depending on length and diameter and the required mechanical strength which, in turn, is dependent on intended service application. Support wires, however, conduct heat away from the filamant, also reducing efficacy. To summarize, the best service-life, efficacy compromises are reached with low-voltage, high-wattage, krypton-filled lamps with coiled-coil filaments and a minimum of support wires consistent with necessary mechanical strength of the filament for the intended application.

Spectral Energy Distribution

Figure 21 shows the spectral energy distribution of tungsten at 3,000 K. Three points are significant with respect to this distribution:

1. The distribution is continuous across the entire range of the visible spectrum. Hence, color resolution is not a problem with incandescent lamps. In fact, most individuals feel that incandescent lighting is most "natural" in color because of their past experience with it.

2. The distribution is weaker in the shorter ultraviolet wavelengths where the eye is most sensitive under scoptic conditions (not a consideration in machine lighting).

3. A high proportion of energy is emitted in the infrared region. This energy is easily converted to thermal energy and may cause discomfort problems for personnel in certain circumstances.

Lamp Efficacy Relative to Other Lamps

The efficacy of a typical rough service incandescent lamp applied in mine application is about 14 lm/W. This compares to efficacies of about 26 lm/W for a very high output fluorescent lamp, 53 lm/W for a high output fluorescent lamp, 44 lm/W for mercury vapor lamps, and 75 to 100 lm/W for high-pressure sodium lamps. Hence, incandescent lamps have the lowest efficacy of all mine lamps and the highest power costs for a given light output. However, other advantages, as follows, contribute to their wide use.

Lumen Maintenance

Two mechanisms cause lumen depreciation over the life of an incandescent lamp:

1. Sublimated or evaporated tungsten from the filament condenses on the inner surface of the lamp bulb and absorbs a portion of the light output.

2. Filament sublimation and evaporation result in a thinner, higher resistance filament. This decreases lamp wattage (since power is inversely proportional to resistance) and reduces light output.

Lumen depreciation is generally less for incandescent than other mine lamps; typically a 15 pct reduction occurs over lamp life.

Lamp Life

Typical rated service life for incandescent lamps is about 1,000 to 2000 h. Although this is a fraction of the rated service life for gas discharge (fluorescent, mercury vapor, and high-pressure sodium) lamps, the actual realized life differential may be much less under the difficult circumstances of mine application. The reader is referred to chapter 6 for discussion of lamp life and economics in mine application.

Power Requirements

Appropriately selected incandescent lamps can be installed directly across the line on both ac and dc power systems. Auxiliary power conditioning equipment for mine application is minimal, limited to transformers or voltage-drop resistors. Circuit simplicity is a major reason why incandescent lamps are so popular in mine lighting. Additionally, incandescent lamps remain operational when supply voltage fluctuates, although, as outlined in the following, this does affect lamp performance.

Lamp Performance Versus Operating Voltage.—The operating characteristics of incandescent filament lamps vary considerably as the operating voltage is varied from nominal. Lamp life, lumen output, lumens per watt, and watts for an incandescent filament are plotted versus the percent of normal operating voltage in figure 22.

Lamp life is very sensitive to changes in the operating voltage. For example, if a typical 150-W parabolic aluminized reflector (PAR) 38 headlamp is rated by the manufacturer to have an output of 1,730 lm and rated life of 2,000 h at 120 V, the operating life of 2,000 h can be expected if the voltage is held to 120 V. If the voltage is increased to 130 V then, from figure 22, the reduction in life can be computed as follows:

Percent normal voltage = 130 X 100/120 or 108 pct. From the lamp life curve in figure 22 the percent life is 40 pct. Therefore, the reduced lamp life at 130 V would be: Lamp life = 2,000 h X 0.4, or 800 h. If the voltage is decreased to 110 V then the increased lamp life can be computed as follows: Percent normal voltage = 110 X 100/120 or 92 pct. The percent life from figure 22 is 300 pct and the increased lamp life would be: Lamp life = 2,000 X 3.0 or 6,000 h.

Note that this seemingly small voltage variation of 8 pct results in a lamp life variation from 800 to 6,000 h. This example illustrates the significant desirability of limiting overvoltage operation of incandescent lamps, and, if practical, operating these luminaires at reduced voltage.

The lumen output of incandescent lamps also varies greatly with change in operating voltage. Referring to figure 22 and for the preceding example at 130 V, the increased lumen output can be computed as follows: Percent normal volts = 130 X 100/120 or 108 pct. From the lumen curve in figure 22 the percent lumens is 130 pct and the increased lamp lumen output is: Lumen output = 1,730 X 1.3 or 2,249 lm. At 110 V the lumen output is: Percent normal volts = 110 X 100/120 or 92 pct. The percent lumens is 68 pct and the reduced output is: Lumen output = 1,730 X 0.68 or 1,180 lm.

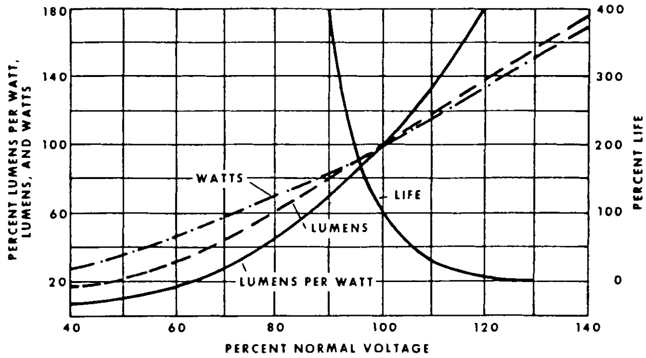


Figure 22.—Effect of voltage variation on the operating characteristics of incandescent filament lamps.

Rough and Vibration Service Lamps.—Where shock and/or vibration occur—typical in-mine lighting application—rough or vibration service lamps should be used. Standard incandescent lamps designed for stationary lighting are simply not applicable for this type of service. The filaments on incandescent lamps become soft and pliable when heated and are readily broken. Rough service lamps employ a multiple filament support construction that provides resistance to filament breakage. These lamps are designed for applications where intermittent shock occurs. Vibration service lamp construction employs tungsten with a special crystalline structure that permits sagging but resists breaking of the filament coils when subject to vibration. Designed for applications where high-frequency, low-amplitude vibration occurs, vibration service lamps offer little shock resistance, and cannot be burned in a horizontal position. The extra filament supports of vibration service filaments are utilized to prevent shorting of the coils when they sag. In general, incandescent lamps utilized on face machines should be rough-service rated. Vibration-service lamps may have application in other areas of the mine where high-frequency, low-amplitude vibration might be found, e.g., pump houses.

Krypton-Filled

In a standard incandescent lamp the bulb is filled with an argon-nitrogen mixture. Some special purpose lamps are filled with krypton gas. As noted previously, the krypton gas conducts heat more slowly from the filament and retards filament evaporation better than the standard argon-nitrogen gas mixture. The result is improved lamp efficacy and increased lamp life. Miners cap lamps use krypton gas-filled lamps to reduce battery drain. Krypton gas may increase efficacy by 7 to 20 pct. Krypton gas-filled PAR 38 lamps are available and some have been tested in mine applications. While significant increased lamp life was reported, the high cost of these lamps (five to six times that of a regular lamp) has limited their use. The life ratings of two available 150-W PAR 38 krypton lamps are 4,000 h compared with 2,000-h life rating for a typical 150-W standard PAR 38 lamp. Lumen output of these particular krypton PAR 38 lamps is slightly less than the standard PAR lamp.

Tungsten-Halogen

A tungsten-halogen incandescent lamp differs from the standard incandescent lamp in that the light source is housed in a small quartz bulb (quartz bulbs offer greater heat resistance than milk-glass used in standard incandescent lamps) that contains a tungsten filament and is filled with a halogen gas such as iodine.

Normally, tungsten, as it evaporates from a filament, is deposited on the inner surface of a bulb and causes blackening. In the halogen lamp, the evaporating tungsten combines with the halogen gas and forms a tungsten-halogen compound that continues to circulate within the bulb. As the compound circulates near the filament, it is broken down and tungsten is redeposited on the filament. This process, called the tungsten-halogen regenerative cycle, increases lamp life and significantly reduces lumen depreciation over the life of the lamp. For example, the rated life for a particular 150-W PAR 38 tungsten-halogen lamp is 4,000 h compared with 2,000 h for a standard 150-W PAR 38 lamp. Note that the temperature of the quartz jacket is very high (about 500° F) because of its proximity to the heated filament. This high temperature must be maintained to prevent deposition of the tungsten-halogen compound on the bulbs.

FLUORESCENT LAMPS AND BALLASTS

Principle of Operation

The fluorescent lamp (fig. 23) is classified as an arc discharge light source. The lamp is filled with mercury vapor and a small amount of inert gas. The cathodes are covered with an electron-emissive material (i.e., a material that produces abundant free electrons when heated), and a fluorescent material (phosphor). When the lamp is energized, passage of electric current through the cathodes causes them to heat and release electrons. Voltage across the lamp causes these electrons to travel at high speed from one cathode to the other in the form of an electric arc. During the arcing process, these electrons collide with the gaseous mercury atoms, energy is absorbed and valence electrons in the mercury atom are shifted to a higher orbit. After time, these displaced electrons fall back to their original orbits, and they release electromagnetic energy, primarily at discrete wavelength bands in the ultraviolet portion of the spectrum. The ultraviolet energy is, in turn, absorbed by the phosphor coating which reemits the ultraviolet energy as electromagnetic energy in the visible portion of the spectrum. The color (wavelength mixture) of visible light produced depends upon the chemical composition of the phosphor coating. Fluorescent lamps, like the other gas discharge lamps, require use of supplementary devices called ballasts for proper lamp operation.

Types

Several categories of fluorescent lamps exist today, differing primarily in the technique utilized for lamp starting. The earliest fluorescent lamps were of the "preheat" type, which required the use of a starter. With this lamp type, the cathodes are preheated to emit electrons to aid in the striking of the arc at lower voltage. The starter is an automatic device that applies current to the cathodes for a period long enough to adequately heat them and then opens to stop the current flow and allows full voltage with an inductive spike to be applied across the two cathodes.

"Instant start" lamps were developed next, primarily as an attempt to overcome the slow starting of preheat lamps. They rely on a very high starting voltage (400-1,000 V) to start the arc without cathode preheating. This simplifies auxiliary circuit requirements, but the required ballasts are large and expensive. The high-voltage starting requirement prevents application of instant start lamps in mining because it might present a potential shock or ignition hazard.

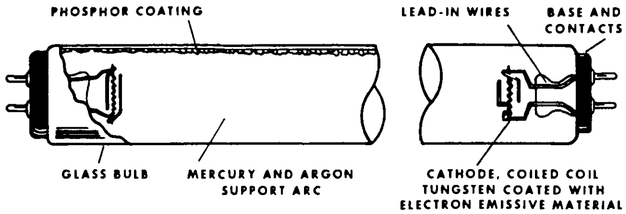


Figure 23.—Construction of typical fluorescent lamp.

Rapid-start lamps start quickly without the use of a starter. They are constructed utilizing continuously heated cathodes with low electrical resistance. The continuous heating is provided by special windings in the lamp ballast. Starting time for rapid-start lamps is almost as fast as instant-start lamps. The lamp circuit is more complicated than an instant-start lamp circuit but the ballast is smaller and cheaper because voltage requirements are reduced. All U.S. fluorescent mine lighting systems use rapid-start lamps, and they will be the emphasis of the remaining discussion of fluorescent lamps.

Performance Characteristics

Lamp Efficacy

Fluorescent lamps are much more efficient than incandescent lamps in the conversion of electric energy to visible energy. Only high-pressure sodium lamps offer greater efficacy among the lamps applied in underground coal mining application. High efficacy offers advantage not only in power costs but also permits cooler operating temperature, an important consideration in the design of mine lighting fixtures. Note that in some cases, fluorescent mine lamps are driven at high frequency via solid-state ballasts. This further improves efficacy relative to standard 60-cycle lamp drive.

Surface Intensity

The entire bulb acts as the apparent light source on fluorescent lamps rather than the small filament or arc tube on other types of mine lamps. Since average lamp surface intensity is equal to the total emitted lumens divided by the apparent surface area of the source (IC 9073, chapter 2), surface intensity is generally lower for fluorescent lamps. This may offer advantage with respect to glare in some design instances, but other factors must be considered for a complete assessment (see chapter 4 of IC 9073 and chapter 5 of this report).

Lumen Output: Standard, High, and Very or Super High

Because large fixtures are not desirable in mine application but high lumen quantities are often necessary, there is incentive for application of fluorescent lamps with high lumen output per unit size. Standard 1-in-diam lamps are driven at 10 W/ft at a current of 430 mA. If special design features are incorporated to regulate mercury vapor pressure at higher temperature, rapid-start lamps can be driven at higher current levels, producing more light from a given size lamp. High output (HO) 1-in-diam lamps are driven at 14 W/ft at 800 mA and very or super high output (VHO or SHO) lamps are driven at 25 W/ft at 1,500 mA. This increases light output significantly, but there is loss in efficacy, especially in the case of VHO-SHO lamps. Because of higher cost and surface intensity (which may require more diffusion), lower efficacy and lamp life, and greater lumen depreciation, VHO-SHO lamps should be applied only in instances where high-lumen output is necessary and achievement of design objectives through use of additional luminaires is undesirable.

Lumen Maintenance

Both deterioration of the phosphor coating and lamp blackening (caused by sputtering of the electron emissive coating from the cathodes through collision of arc particles), cause lumen depreciation during the life cycle of a fluorescent lamp. Lumen depreciation is very high (up to 10 pct) during the first 100 h of lamp operation. Because of this, manufacturer lumen ratings are based on performance after 100 h of lamp burn. This fact should be taken into account when designing systems in simulators or measuring light output with new lamps. Lumen depreciation is about 18 pct of the 100-h lumen output value for standard fluorescent lamps over a life span of 20,000 h. Lumen depreciation of HO and VHO-SHO lamps is about 23 pct and 27 pct over 9,000- and 7,500-h service lives, respectively. Note, however, that the rate of lumen depreciation is much higher in the early portion of the life cycle of these lamps. However, since their life is shorter, this factor diminishes end-of-life differences relative to standard lamps.

Spectral Energy Distribution

As implied, different lamp spectral distributions can be obtained with different phosphor coating mixtures. Figure 24 shows distributions obtained for some of the standard mixtures. As can be seen, emission occurs in a continuous band with exception of peaks at certain discrete wavelengths. These peaks represent direct radiation in the visible spectrum from the mercury discharge and comprise only about 10 pct of total lumen output. Because of the well-balanced, continuous nature of the curve across the entire visible spectrum, color resolution is not a problem with fluorescent lamps. Note that lamps with higher emission in the red portion of the spectrum (e.g., Deluxe Warm White) tend to appear more "natural" (i.e., closer to sunlight and incandescent light with which we are most familiar). This is realized, however, at some loss of efficacy and because of the importance of high efficacy in many mine applications, the lamps utilized are generally standard Cool White.

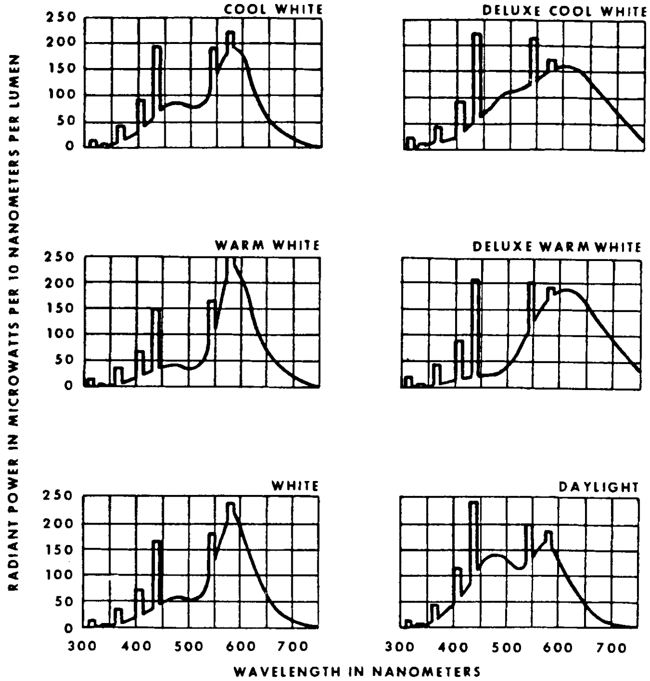


Figure 24.—Specular energy distribution curves for common fluorescent phosphor mixtures.

Lamp Life

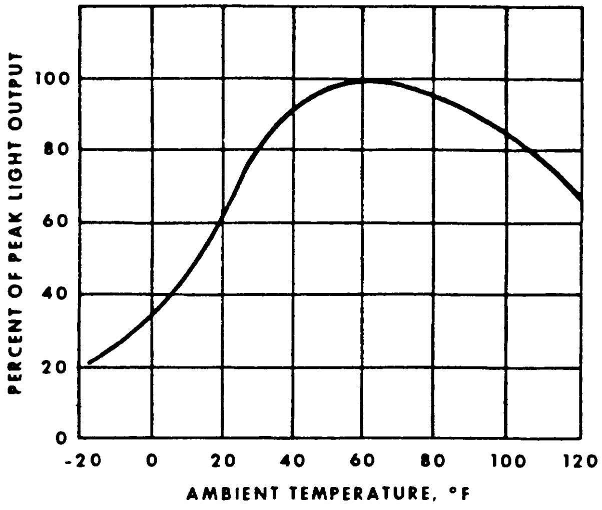
Fluorescent lamps typically have a much longer rated life than incandescent lamps. The rated life of typical rough or vibration service incandescent lamps is approximately 1,000 h. The rated life of typical fluorescent lamps applied in mines range from 7,500 to 20,000 h. Note that the shorter life values apply to the VHO-SHO and the HO lamps, and the longer values apply to standard fluorescent lamps. "Normal" fluorescent lamp failure is due to the depletion of the electron-emissive material on the cathodes. This material degrades more rapidly during the starting cycle. Usually, fluorescent lamp life ratings are based on one start every 3 h. Accordingly, more frequent starts will tend to decrease lamp life, while less frequent starts will increase it. The cathode filaments in fluorescent lamps are of rigid construction and less prone to failure under shock and vibration conditions than their incandescent counterparts. Performance requisites posed by mine application, both electrical and mechanical, can be severe; hence rated life figures are not reliable for comparing mine lamps. Chapter 6 discusses factors causing premature lamp failure, compares the performance of different lamp types under these conditions, and suggests remedies if problems are encountered.

Lumen Output as a Function of Lamp Temperature

The light output of a fluorescent lamp varies with the temperature of the bulb wall. This temperature affects the vapor pressure of the mercury, which changes the light output. The change in light output of a typical HO fluorescent lamp as a function of ambient temperature in still air is shown in figure 25. Note that both high and low temperatures can reduce light output. This curve illustrates the importance of allowing sufficient warmup time when measuring illumination levels in fluorescent lighting systems and the importance in considering operating temperature in the design of efficient lamp enclosures.

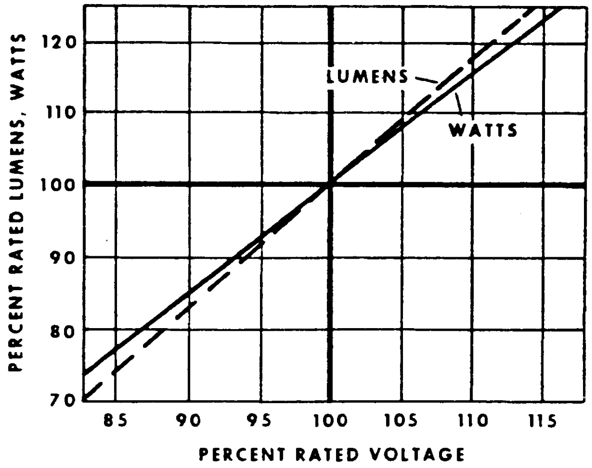
Effect of Voltage

Overvoltage operation of fluorescent lamps produces an arc at higher than rated current. This deteriorates the electron-emissive cathode coating, causing lamp blackening, reducing life, and increasing the rate of lumen depreciation. Conversely, low voltage may be insufficient to heat the cathode, greatly prolonging the starting procedure (especially in humid conditions). This condition is especially destructive of the emissive coating, significantly reducing lamp life. Figure 26 shows lumen output and



FOR A TYPICAL HIGH OUTPUT FLUORESCENT LUMINAIRE IN STILL AIR

Figure 25.—Change in light output of a fluorescent lamp as a function of ambient temperature.



FOR A 2-LAMP RAPID START BALLAST

Figure 26.—Change in light output and wattage of a fluorescent lamp as a function of line voltage.

wattage versus percent nominal line voltage for a typical fluorescent lamp. It can be seen that both undervoltage and overvoltage reduce efficacy (although the effect is not as significant as for incandescent lamps). Also, sudden voltage drops can extinguish the lamp arc. Because of these effects, and the fact that ballast life is also affected by voltage variation, it is important that fluorescent lamp circuits be specified that are compatible with the character of the existing voltage supply.

Flicker

In the past, stroboscopic effect caused by lamp flicker (IC 9073, chapter 3) could create a serious hazard in industrial application of fluorescent lamps. Although the lamp arc is generated at 60 c/s, the phosphors exhibit a phenomenon called "phosphorescent action" which causes light transmission to continue or "carry over" during the periods of the cycle where mercury discharge activity is low or zero. In modern lamps the level of carry-over is very high, minimizing output variations; hence, stroboscopic effect is generally not a problem. Stroboscopic effect can be serious, however, near the end of lamp life or when the circuit is not functioning properly. Proper maintenance of fluorescent systems is important to prevent this problem from occurring. Connection of ballasts across alternate leads of a three-phase supply is an additional precaution to further smooth output variations since one lamp of the circuit operates at its "peak" while the other is at its "valley" (most fluorescent mine lighting circuits are not set up this way, however).

Fluorescent Ballasts

Fluorescent, as well as the other arc discharge lamps, cannot be operated directly across a voltage supply because all arc discharge lamps exhibit what is known as a negative resistance characteristic. If connected directly across a voltage source and the arc is initiated, electrical resistance across the lamp decreases and lamp current flow increases with time. This continues, and in just a short period of time such a high current level is reached that the lamp is physically destroyed. For successful lamp operation, an auxiliary electrical impedance, the ballast, must be introduced in the line to limit current flow. This is the principle function of all ballasts and the one from which the name of the device was derived. That is, their major role is to stabilize or "ballast" lamp operation at a reasonable energy level.

Ballasts have auxiliary functions in addition to current limiting. In the case of rapid-start fluorescent lamps, the type most frequently used in mine face operations, the important ballast auxiliary functions are (1) provision of a controlled amount of electrical energy to the lamp cathodes to provide an adequate supply of free electrons, and (2) provision of a sufficiently high electrical potential (voltage) across the lamp electrode to assure the initial arc will strike. Note that cathode heating must be provided both before starting and during lamp operation,

Most ballasts use core-and-coil construction. Insulated windings (coils) around an iron core form an inductor that is capable of limiting current flow with relatively small internal power consumption. Two or more windings may be coupled to form a transformer capable of (1) raising line voltage to the level required for striking the arc, and/or (2) regulating the power to the lamp with variations in line voltage. Capacitors are used in conjunction with these basic circuit elements for various purposes including power-factor correction, current regulation, and assistance in lamp starting. These components may be encased and impregnated with a fill compound (e.g., asphalt) which protects the components from the weather, improves heat transfer, and reduces the noise produced by the ballast.

Figure 27 shows the basic circuit employed in the construction of dual-lamp, series-sequence-type, rapid-start ballasts—the most widely applied core-and-coil ballast in underground coal mine lighting. When the ballast-lamp circuit is closed, special windings in the ballast provide a small heating current to the lamp electrodes, liberating electrons and reducing the voltage level required to start the lamp. As can be seen, lamp 2 is shunted by a capacitor. This momentarily places nearly full ballast secondary voltage across lamp 1, causing it to start. Once lamp 1 starts,

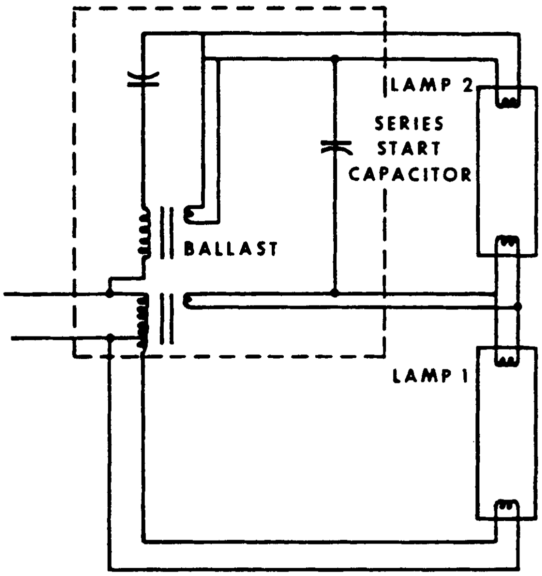


Figure 27.—Dual-lamp, series-sequence-type, rapid-start fluorescent ballast circuit.

the voltage across the lamp drops (i.e., lamp resistance decreases) and nearly full secondary voltage now appears across the shunted capacitor and lamp 2, causing it to start. Once lamp 2 starts, the two lamps operate in series. During a brief warmup period, lamp current will increase in both lamps until stable, hot cathode operation is reached. Now, the system formed by the lamps and ballasts operates in a steady-state condition. Assuming supply voltage is nominal, the electrical operating parameters of the system should be conducive to long component life and good performance at close to nominal lamp operating voltage and current specifications. Note that this dual-lamp ballast is smaller and less expensive than two single-lamp ballasts. However, ballasts that operate more than two fluorescent lamps are generally not economical.

Ballast Heating and Related Design Considerations

Excessive heat is almost always the cause of reduced ballast life in any application. Under normal conditions, an average ballast life of about 12 yr can be expected. A 12-h/d duty cycle is assumed in this rating and should ballasts operate for longer cycles, life is reduced proportionately. For example, if a mine application calls for a 24-h/d duty cycle, expected ballast life is about 6 (12 divided by 2) yr. Chapter 6 discusses the mechanisms of heat-related failure, diagnosis, and remedies involving changing of the application character. The following is a discussion of some design features that affect ballast heating.

For realization of rated ballast life, ballast case temperature should not exceed 90° C and internal ballast coil temperture should not exceed 110° C. Class P ballasts incorporate a thermal protector within the ballast case, which disconnects the ballast from the power line when the internal temperature limit is exceeded. Most ballasts employ an automatic resetting thermal protector that recloses the circuit when ballast temperature falls. This device can reduce the incidence of ballast failure, but it is important that when the device is triggered, the cause of the problem should be isolated and action should be taken to eliminate it. (See chapter 6.)

Ballast case fill compound varies in its ability to conduct heat from the coils. A superior fill material will reduce coil temperature and extend ballast life. Traditionally, ballasts have been filled with asphalt, but many manufacturers offer a material with higher silicon content, which improves heat conductivity and subsequent dissipation. Additionally, asphalt tends to soften when hot, and, depending on ballast mounting position, may separate (sag) from the ballast case and reduce heat transfer. A material that does not soften at high temperature is preferable.

Manufacturers make "premium" ballasts that reduce power consumption and, correspondingly, heat generated by the ballast. This is achieved primarily through the use of larger diameter conductors in the construction of the coils. These ballasts cost more than standard ballasts and are intended for application where adequate heat dissipation is difficult to achieve and/or reduction of energy consumption is desirable. Because of the high incidence of heat induced core-and-coil ballast failure in mining application, ballasts that apply this principle should be sought. Lack of availability, however, is a problem in acquiring some fluorescent mine lamps.

All of these heat-related features are very important in a mining application. Since many of the core-and-coil ballasts available from mine lighting hardware suppliers are off-the-shelf items from the major ballast manufacturers (e.g., Jefferson, Advance Transformer, General Electric, and Universal), it is recommended that the supplier be questioned concerning these features. If the features are not incorporated in the standard equipment, desirable substitutions may be possible.

High-Intensity-Discharge Lamps - High-Pressure Sodium and Mercury Vapor

High-intensity-discharge (HID) lamp types, which are used in mining, include high-pressure sodium (HPS) and mercury vapor (MV) lamps as well as other types such as the various metal halide lamps. The basic light-producing technique is similar to that used in fluorescent lamps—electrons in an electric arc between two lamp electrodes collide with gaseous metallic atoms producing electromagnetic radiation through shift of the metals' valence electron from a high-energy to a low-energy orbit. The major differences in the light-producing process of HID and fluorescent lamps are as follows:

1. The partial pressure of the metal vapor in the HID lamp is higher than the mercury vapor pressure in fluorescent lamps. (HID lamps are often referred to as "high" pressure lamps. The adjective high is relative to the pressure level in fluorescent and low-pressure sodium lamps. Actually, pressure within the lamps is seldom more than twice atmospheric.) This is obtained by confining the arc to a small, insulated tube. The result is that the wavelengths of the light energy produced tend to be longer (note that fluorescent lamps produce initially in the ultraviolet region), and although still at discrete regions, the wavelength band at these regions is broader.
2. Since the electromagnetic energy produced is in the visible range, phosphors are not required to convert the energy to wavelengths in the visible portion of the spectrum.

3. The arc is operated at higher energy density than the fluorescent lamp arc, enabling greater lumen output from a physically smaller lamp.

HID lamps include the most efficient, compact, and long-lived light sources available. The operating characteristics of the two HID lamps applied in underground mining application—mercury vapor and high-pressure sodium—are discussed in the following sections.

MERCURY VAPOR LAMPS

Functional Description

Figure 28 shows the component parts of a mercury vapor (MV) lamp. The arc tube is where the light is produced. It consists of two operating electrodes with an electron-emissive coating, a starting electrode, some liquid mercury, and argon gas. A ballast is required to provide proper voltage and current to the lamp at the various phases of the lamp operating cycle.

When the lamp is started, a voltage is placed across (1) the lower operating electrode and the adjacent starting electrode, and (2) across the two operating electrodes. Argon gas is readily ionized between the lower operating and the starting electrodes at this potential and an arc is formed between these two electrodes. A resistor in series with the starting electrode limits current flow through the arc.

Heat is the important byproduct of the argon arc and, as time passes, it vaporizes more and more of the liquid mercury. This lowers the resistance across the two operating electrodes to a point where the arc across the operating and starting electrodes is supplanted with an arc across the two operating electrodes. This arc produces visible electromagnetic energy via the arc discharge process discussed in the preceding section.

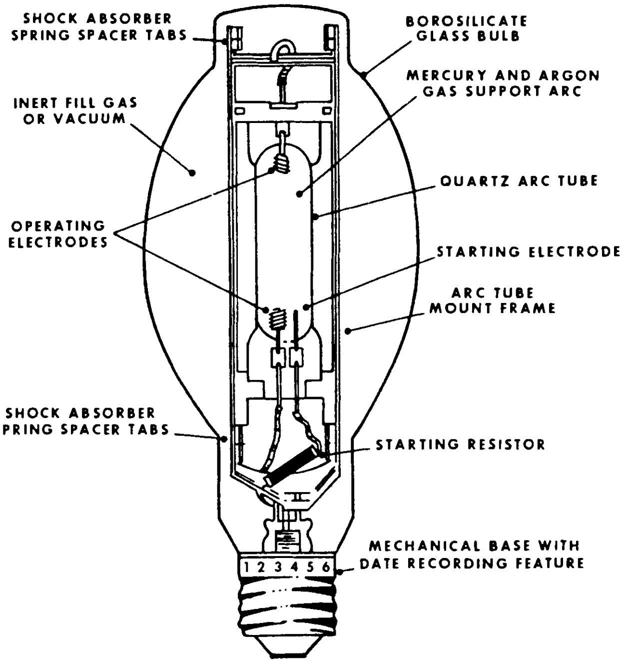


Figure 28.—Typical mercury vapor lamp construction.

After this main arc is initially struck, more and more of the mercury vaporizes and more light is produced until a steady-state condition is reached when all the mercury has been vaporized. The time until the lamp reaches steady-state operation is called the warmup period and takes from 5 to 7 min.

A large dip in voltage level or dropout of the supply voltage lasting one-half cycle or longer causes the conducting electrons in the arc to neutralize and extinguishes the arc. In this circumstance, the arc will not restrike immediately because of the high vapor pressure in the lamp, which prohibits reignition of the argon arc. A cooling down period (3-10 min) is necessary until the starting cycle can be initiated again.

The arc tube is constructed of quartz fused silica to withstand the high temperatures. The outer bulb serves the purposes of (1) containing an inert (nitrogen) atmosphere around the arc tube to prevent oxidation of the leads and supports, which would occur at high temperature in an oxygen environment, (2) maintaining proper temperature of the arc tube and regulating mercury vapor pressure, and (3) absorbing ultraviolet radiation produced by the lamp so that is not transmitted to the environment.

Efficacy-Lumen Output

Lumen depreciation over the service life of MV lamps is high relative to the other lamps used in mine application, ranging from 30 to 45 pct. Note, however, that this depreciation occurs over a very long life. The *rate* of depreciation is not excessive and high depreciation may not be an important consideration in applications where realized service life is greatly diminished from rated life. Like the other arc discharge lamps, lumen depreciation is highest during the first 100 h and rated initial lumen output is at the 100-h point. The primary mechanism that causes lumen reduction is the "sputtering off" of electron emissive material when arc particles collide with the electrode. This material is deposited on the arc tube where it absorbs a portion of the generated light. A low number of burn hours per start accelerates lumen depreciation.

Spectral Energy Distribution

MV lamps emit most of their light at four discrete wavelengths (fig. 29). Although these wavelengths are spread across the spectrum providing reasonable color resolution for most applications, the spectral emission curve is not continuous. As a result, orange- and red-colored objects appear brownish and this may deter color code resolution on materials such as blast and electrical wiring if MV lamps are the primary source of illumination. Note that MV lamps are available with a phosphor coating on the inside of the outer bulb. This coating converts ultraviolet radiation produced by the lamp into visible radiation similar to the process in effect on fluorescent lamps. This improves efficacy and smooths wavelength distribution somewhat.

Lamp Life

MV lamps have the longest rated life of all the mining lamps (16,000-24,000 h). Note that because of lumen

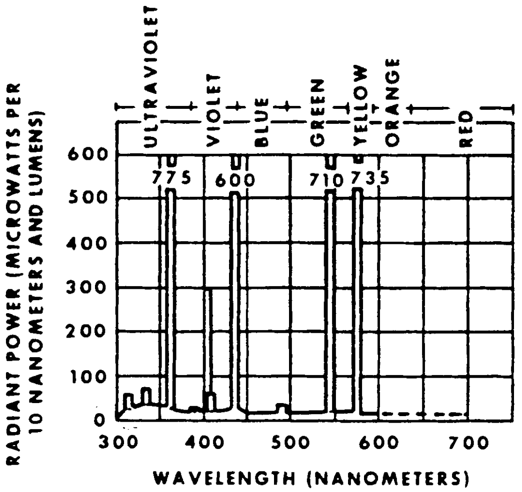


Figure 29.—Spectral energy distribution of a typical clear mercury vapor lamp.

depreciation, rated life values are normally given for the point where only one-third of the lamps have failed. The sputtering of electron emissive material (previously discussed) raises steady-state lamp operating voltage above the voltage available from the ballast, ending lamp life. Short burn periods and frequent lamp starting will accelerate this mechanism and decrease lamp life. Other factors affecting lamp life are discussed in the following sections.

Effect of Voltage Variation

Increases in line voltage applied to an MV lamp and ballast-and-lamp system increase the wattage consumed by the lamp. This, in turn, increases the temperature of the arc tube, which can have the following effects:

1. If wattage is especially high for a long duration, the arc tube may bulge or shatter, ending lamp life.
2. Sputtering of the electron emissive coating is increased, accelerating lumen depreciation and reducing lamp life.

Continuous operation at low voltage makes restarting of the lamp arc at every half cycle more difficult. This also increases the rate of sputtering of the electron emissive coating, which reduces lamp life and increases lumen depreciation. Short-duration voltage fluctuations have little effect on lamp life and lumen depreciation. However, as noted previously, excessive voltage dips or dropouts, even for as short a duration as one-half cycle, can cause the lamp arc to extinguish and a long delay is incurred until the lamp again becomes operable. On machine-mounted installations, these dips are frequently encountered and this serious operational problem has limited the use of MV lamps on face machines. The choice of a ballast has significant effect on the impact of voltage variation on mercury lamp performance, and this matter is discussed in a subsequent section.

Flicker

Lumen output drops to zero every half cycle on an MV lamp. Potentially, the stroboscopic effect (IC 9073, chapter 3) could be a significant problem. To minimize this effect, the vicinity where such an effect might occur should be illuminated with two lamps on a lead-lag ballast with low-current crest factor or by two lamps or more on separate phases of a three-phase circuit. Phosphor-coated lamps present less of a flicker problem than clear lamps because of the presence of the phosphorescent action discussed previously.

Ballasts

MV lamps, like the fluorescent lamps discussed previously, exhibit a negative resistance characteristic and must be ballasted to limit current flow through the lamp. An additional function performed by the ballast is to supply a high voltage across the main and starting electrode to initiate the starting arc and, subsequently, to initiate and sustain the main arc. Numerous ballast designs are available for MV lamps and they are summarized in figure 30. They differ in the following characteristics:

Cost.—The more windings and material required, the more expensive the ballast. Utilization of a capacitor also increases ballast cost.

Starting Versus Operating Current.—With some ballast designs, starting current is higher than operating current. With others, the reverse is true. This impacts sizing of conductors and fusing-circuit breaker requirements.

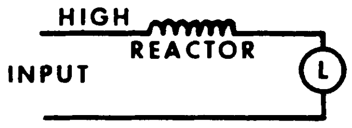
Power Factor (PF).—High-PF electrical equipment is generally more desirable than low-PF equipment because current requirements to deliver a given level of power are reduced. This reduces the required size of conductors and, accordingly, reduces wiring costs. Available ballast and lamp designs differ in the inherent PF under which the system is operated. On those designs with inherent low PF, improvement can be achieved through the addition of a PF-correcting capacitor. However, the cost of the capacitor may make it more advantageous to go with a design with an inherently good PF.

Crest Factor.—Crest factor on an ac system is the ratio of peak voltage or current to the root-mean-square (RMS) value, which represents the "average" value. For a standard sinusoidal waveform, crest factor is 1.41. High-intensity discharge lamp ballasts are generally designed to distort the waveform so the voltage crest factor is higher than 1.41. This enables one to provide a sufficient peak voltage to start the arc with a lower cost ballast. Moreover, if properly designed, RMS voltage for a high voltage crest factor waveform will not greatly exceed that for a lower voltage crest factor waveform and this is important in sustaining the arc. Although high-voltage crest factor is generally desirable, high-current crest factor is not. It can increase flicker problems, accelerate lumen depreciation (by increasing sputtering), and reduce lamp life.

Line Voltage Regulation.—The effects of variation of supply voltage levels on the lamp-ballast system differ greatly depending on ballast design. Some designs can tolerate wide variation with minimal effect whereas others must be operated close to nominal. The impact on lumen depreciation, lamp life, lumen output, and ballast life is very significant. Because of the tendency for mine power systems to be poorly regulated, this factor should be given great attention.

Extinction Voltage.—Probably the most important consideration regarding the application of MV lamps to mining application is the ability of the lamp-ballast system to tolerate voltage dips without extinguishing the lamps and necessitating recycling. Ballasts vary greatly in their ability to "ride through" voltage dips.

As can be seen in figure 30, regulator and autoregulator ballasts offer the best performance, especially with respect to voltage regulation and extinction voltage, which are so important in mining application. Most mine lighting suppliers provide autoregulator ballasts because of the combination of reasonable cost and performance. However, the performance edge of regulator ballasts, especially with respect to lamp extinction, may justify the extra cost of these ballasts in some case. Note that they are off-the-shelf items for the MV lamps used in mining application and may be substituted for autoregulator ballasts.

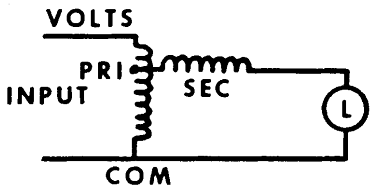


REACTOR

Simplest mercury ballast design. Consists of a wire coil around an iron core that serves as a reactor or "choke." Function is simply to limit current to the lamp. Voltage requirements for starting are provided by the line. A capacitor may be used to improve power factor.

Advantages:
Inexpensive.
Low internal power consumption.
Low current crest factor.
Quick lamp warmup.

Disadvantages:
Poor regulator of line voltage variation, ±5 V limit.
Will tolerate only 15 pct voltage dip for a maximum of a few cycles.
Higher lamp starting than operating current.
Low power factor (50 pct) unless corrected.
Line voltage must be adequate for lamp starting; particular problem for higher wattage lamps.

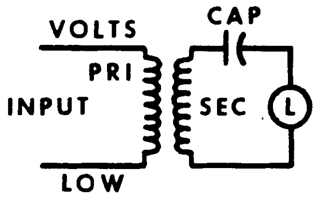


LAG (AUTOREACTOR, AUTOTRANSFORMER)

Principle of operation is same as reactor ballast, the only difference is that it is configured as an autotransformer to boost voltage to levels required to initiate and maintain arc. This ballast may be power-factor corrected with a capacitor but cost is comparable to the autoregulator ballast, which offers better performance.

Advantages:
Same as reactor ballast.

Disadvantages:
Same as reactor ballast except lag ballasts can operate high-wattage lamps on low-voltage supply circuits.

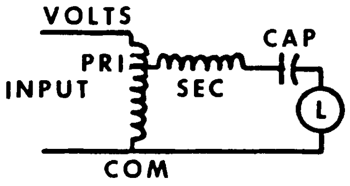


REGULATOR (CONSTANT WATTAGE)

Constructed with two electrically isolated windings similar to a transformer. Configuration can raise voltage level for lamp, if necessary. Current limiting accomplished by secondary winding (magnetically saturated) and a capacitor in series with lamp. Power factor is leading not lagging, unlike reactor and lag ballasts.

Advantages:
Excellent voltage regulation, ±13 pct change in line voltage changes lamp wattage ±2 pct.
Will tolerate 50 pct voltage dips for 4 s without lamp extinction.
Inherently high power factor (90 pct).
Lower starting than operating current.
Isolation from mains reduces shock hazard.

Disadvantages:
Expensive.
Somewhat higher current crest factor.



AUTOREGULATOR (CONSTANT WATTAGE AUTOTRANSFORMER)

Combines lag and regulator ballast principles. Constructed as autotransformer with a capacitor in series with lamp. Coils and capacitor provide current limiting, whereas autotransformer design provides voltage boost. Considerable coupling of primary to secondary provides reasonable regulation. Power factor is leading.

Advantages:
Moderate cost.
Reasonable voltage regulation, ±10 pct change in line voltage changes lamp wattage ±5 pct.
Inherently high power factor (90 pct).
Starting current usually lower than operating current.

Disadvantages:
Somewhat high current crest factor.
No isolation between primary and secondary.

Figure 30.—Mercury vapor lamp ballasts.

HIGH-PRESSURE SODIUM LAMPS

Principle of Operation

Figure 31 shows the construction of a high-pressure sodium (HPS) lamp. The arc tube is smaller in diameter than the arc tube of an MV lamp and is made of a translucent high-transmissivity, polycrystalline-alumina ceramic. Contents of the arc tube include two operating electrodes, mercury-sodium amalgam, and xenon gas. The tube is small in diameter, confining the arc so that the high temperatures necessary to vaporize sodium are more readily obtained. The special ceramic is necessary to withstand the heat and resist sodium attack. (Materials engineering of the arc tube and its interconnection to the power leads was a major feat in the development of HPS lamps because of the high temperature and presence of free sodium.) The small tube diameter prevents use of a starting electrode to obtain warmup as is used on MV lamps. In the case of HPS lamps, a special ballast circuit is utilized to provide a short-duration, high-voltage spike across the main electrodes, which readily ionizes the xenon gas. (Note that because of its short duration, this spike is low energy.) Similar to the arc process of an MV lamp, the xenon arc vaporizes the amalgam that enters the arc stream. Lumen output increases until a steady-state operating condition is reached in about 3 min.

Like MV lamp arcs, the arc HPS lamp will extinguish if the voltage dips. However, the necessary degree of cooling and time requirements to restrike the arc are considerably less than those required on MV lamps (approximately 1 min versus 3-10 min). With special starting aids, this time can be reduced to almost zero. Also, there is another important difference between MV and HPS lamps. Since at steady-state operation in an MV lamp all the mercury is vaporized, arc tube pressure and lamp operating voltage remain relatively constant over lamp life. In an HPS lamp there is excess amalgam and throughout lamp life changes occur that increase arc tube temperature and pressure. This increases the amount of amalgam that is vaporized and increases lamp voltage. Ballasts must be designed to accommodate this voltage change, and, as will be discussed, it has impact on lamp failure.

Efficacy-Lumen Output

HPS lamps have the highest efficacy of the mine lamps applied at the coal face. In fact, HPS lamps have the best efficacy of all the polychromatic-wavelength lamps available; only monochromatic, low-pressure sodium lamps have higher efficacy. Like MV lamps, HPS lamps offer high lumen output in a compact source. In very high seams, they may be the only practical source for meeting light level requirements. The low wattage HPS lamps (e.g., 50-70 W) have significantly lower efficacy than the higher wattage (100-150 W) mine lamps.

Lumen Depreciation

The mechanism of lumen depreciation in HPS lamps is similar to that of MV lamps. However, lumen depreciation of HPS lamps is very low considering their long life. Mean lumens average only a small fraction below initial lumen rating and net lumen depreciation is about 20 pct. The changing lamp wattage characteristic over the life of an HPS lamp has the effect of maintaining near constant lumen output for about the first 40 pct of lamp life (depending on the ballast design), and the rate of depreciation increases from this time onward. Note that published lumen depreciation curves for HPS lamps measure lumen output at constant lamp wattage. They are *not* representative of field performance because of the changing lamp wattage characteristic.

Spectral Energy Distribution

At the high pressure and temperature levels in the HPS arc tube, an effect called self-reversal improves the spectral character of the light emitted by HPS lamps. The natural emission of sodium in the visible spectrum is at two closely spaced wavelengths, 589.0 and 589.6 nm. In the self-reversal process, the sodium absorbs the 589.0- and 589.6-nm light and rebroadcasts it at higher and lower wavelengths. The net effect is a continuous emission somewhat weak in the shorter (blue and green) wavelengths. HPS lamps have a golden white tone (see figure 32). Color rendition can be a problem with HPS lamps, but they do permit better rendition than MV lamps.

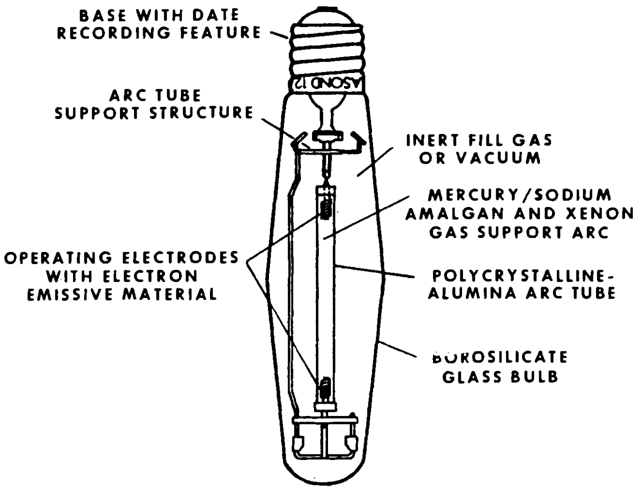


Figure 31.—Typical high-pressure sodium lamp construction.

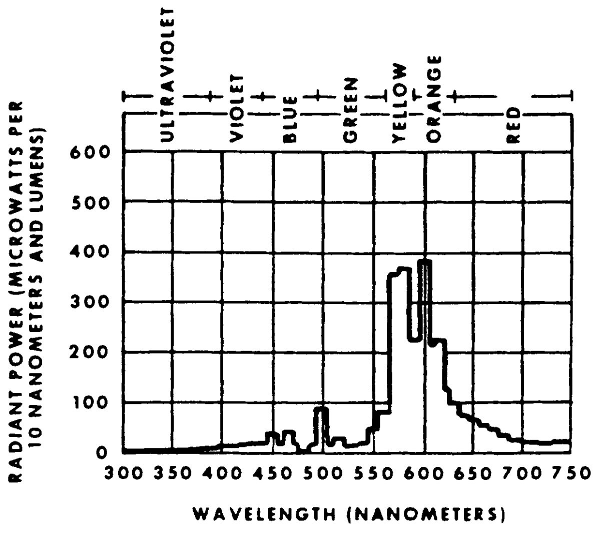


Figure 32.—Spectral energy distribution of typical high-pressure sodium lamp.

Lamp Life

HPS lamps have very long rated lamp life, 24,000 h. As previously noted, the mechanism of normal lamp failure involves the changing voltage character of the lamp throughout its life. The steady-state lamp operating voltage rises above that which is available from the ballast. Note that a failed lamp will continue to start and warmup. However, once the voltage to sustain the arc rises above that available from the ballast, the arc will extinguish. If the power is not turned off, an HPS lamp that has failed in this manner will continue to cycle on and off.

Effect of Voltage Variation

Like all other mine lamps, the effect of high line voltage is detrimental to lamp life. High line voltage (1) raises the steady-state lamp operating voltage and wattage and shortens the period that the available ballast voltage is sufficient to start the lamp arc, decreasing lamp life; and (2) accelerates the mechanisms that cause lamp voltage rise and this also reduces lamp life. High-energy voltage transients tend to damage the leads in the outer bulb. Sustained high-voltage operation has little effect on efficacy, but does accelerate lumen depreciation. Like MV lamps, severe voltage dips or voltage dropouts can extinguish the HPS lamp arc. Restrike, however, can be achieved instantly with special starting aids.

Flicker

Like MV lamps, lumen output drops to zero every half cycle on HPS lamps and the stroboscopic effect can be a problem in some applications. Connecting these lamps to alternate leads of a three-phase power supply is one way to prevent this problem.

Ballasts

The function of HPS ballasts differs significantly from that of MV ballasts. One difference involves provision of a high-voltage, short-duration pulse to initiate the xenon arc when starting the lamp. This is provided by an auxiliary device called a starter or striker. The second difference involves varying lamp operating characteristics (voltage and wattage), which are dependent on several factors. HPS lamp ballasts should be capable under these changing characteristics of maintaining lamp electrical operating parameters within certain limits consistent with reasonable lamp performance and life. As a result, HPS ballasts are generally larger and more expensive than their MV counterparts.

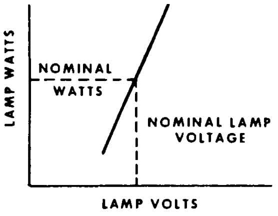
Three factors contribute to varying lamp electrical operating parameters:

1. HPS lamps exhibit large lamp operating voltage increases (or decreases) as lamp wattage increases (or decreases). This occurs because HPS lamps have excess amalgam, and, as lamp wattage increases, more amalgam is vaporized. MV lamps, on the other hand, have no excess arc metal, and lamp voltage remains relatively stable with increases in wattage. The implication of such a lamp wattage-voltage relationship is that it is important that HPS lamp ballasts be capable of limiting lamp wattage changes with changes in line voltage.

2. As noted, HPS lamp operating voltage increases as the lamp ages. This effect is caused by several factors. First, increased arc tube blackening throughout lamp life raises arc tube temperature and pressure. This, in turn, increases the level of amalgam that is vaporized and, hence, raises lamp steady-state operating voltage. Additionally, some of the sodium material will react with arc tube components, changing the ratio of sodium to mercury in the amalgam, which also raises operating voltage. Even if lamps can be operated at constant wattage throughout their life, lamp operating voltage will gradually increase and eventually will exceed that available from the ballast, ending useful lamp life.

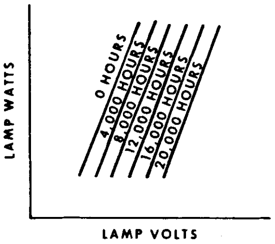
3. At nominal operating wattage, the range of lamp operating voltages is wide for new lamps. HPS lamp manufacturing techniques are not so refined that narrow electrical performance specifications can be obtained at a reasonable unit manufacturing cost. Impurities, slight changes in arc tube cold spot temperature, material variances, etc., make precise manufacturing control impossible. Typically a ±15-pct range in voltage is accepted as nominal lamp wattage.

Figure 33 summarizes the effect of these factors. Figure 33*A* shows the wattage-voltage character of the lamp. The increasing steady-state operating voltage throughout lamp life has the effect of causing the line to "march" to the right over time as depicted in figure 33*B*. The manufacturing variances impact the starting point of the march as depicted in figure 33*C*.



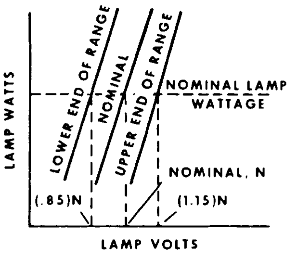
AS LINE VOLTAGE INCREASES, LAMP WATTAGE AND LAMP VOLTAGE INCREASE AS DEFINED BY THIS LINE.

A. EFFECT OF WATTAGE VARIATION (WHICH MAY RESULT FROM CHANGING LINE VOLTAGE) ON LAMP OPERATING VOLTAGE



VOLTAGE-RISE CHARACTERISTIC DISPLACES WATTAGE/VOLTAGE OPERATING LINE TO THE RIGHT AS THE LAMP AGES.

B. EFFECT OF LAMP VOLTAGE RISE RESULTING FROM LAMP AGING



MANUFACTURING TOLERANCES AFFECT STARTING POINT FOR THE RIGHTWARD "MARCH" OF WATTAGE/VOLTAGE LINE AS LAMP AGES.

C. EFFECT ON MANUFACTURING TOLERANCES

Figure 33.—Lamp characteristics that must be accommodated in high-pressure sodium lamp ballast design.

Because of these effects, lamp manufacturers have set up specifications for HPS ballast performance in the form of a trapezoid diagram (fig. 34). These diagrams define the maximum allowable variations in lamp voltage and wattage that the ballast may permit. The minimum lamp wattage is the minimum wattage at which the lamp will provide reasonable lumen output. The maximum wattage line is the maximum figure 34 wattage at which the lamp can be operated and still have reasonable life and lumen depreciation rates. The minimum voltage line is defined by the lower end of tolerated manufacturing range; e.g., for a 100-V nominal lamp, this line intersects 85 V (0.85 X 100) at nominal lamp wattage. The maximum voltage line is placed at the maximum voltage level at which the ballast can reasonably be expected to provide adequate voltage to keep the lamp operating. Once lamp steady-state voltage requirements exceed this level, the lamp has failed.

Superimposed on the trapezoid diagram is a ballast characteristic curve (fig. 35*A*). This haystack shaped curve depicts how a particular ballast design will operate a lamp (i.e., at what lamp wattage levels) as lamp voltage changes during its life. Note that the curve stays within the confines of the trapezoid. When line voltage increases or decreases, the ballast characteristic curve will shift up or down accordingly but will not change significantly in shape.

The shape of the curve varies depending on ballast design and is useful in evaluating performance of the resulting ballast-lamp system (fig. 35*A*). The ideal ballast characteristic curve would be a horizontal line at nominal lamp wattage and would not shift up or down for changes in line voltage. Such a ballast would be too expensive to manufacture. However, some moderately priced ballasts maintain lamp performance close to this line with a relatively small hump. The amount of vertical shift of the ballast characteristic curve with changes in line voltage also varies depending upon ballast design (fig. 35*B*). Ballasts that yield curves with less of a hump and less vertical shift are preferred to those with a high hump and large vertical shift because they have better regulation ability. Some ballasts yield a characteristic curve that rises significantly above the nominal lamp wattage line as lamp voltage rises (fig. 35*C*). These ballasts will accelerate lamp failure because continued lamp operation at high wattage will accelerate the rate of lamp voltage rise and shorten the period until available ballast voltage is insufficient to maintain lamp operation.

There are three main categories of HPS ballast designs. These are depicted in figure 36 along with a discussion of the shape of their ballast characteristic curve and their relative performance advantages and disadvantages. Frequently, lag ballasts are provided for mine application of HPS lamps. Although less expensive, they perform poorly on applications where line voltage tends to fluctuate. Lead ballasts are preferable; they offer reasonable performance, especially with respect to line voltage variation, at moderate cost. Regulator ballasts may better maintain good lamp life for operation at high line voltage but care must be taken in heat sinking these ballasts, and they may not be available for certain mine lamps. Mine hardware suppliers should be contacted concerning ballasts substitution if deemed desirable.

Instant-restart starting aids are available for HPS mine lamps and they reduce the time duration of lamp outages caused by voltage dips to a fraction of a second. It is recommended that users request these devices when purchasing HPS hardware.

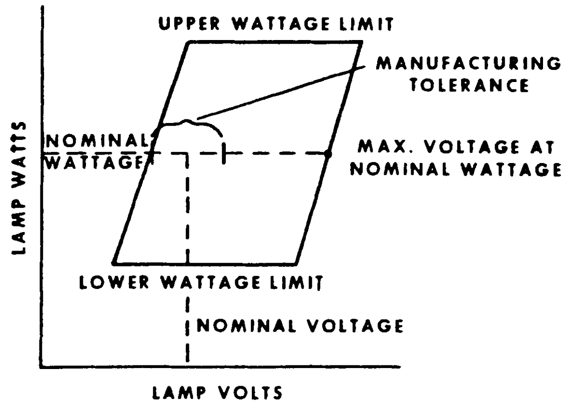
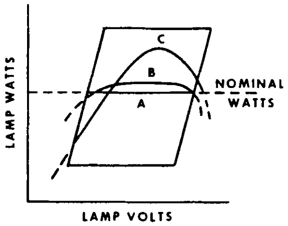


Figure 34.—Trapezoid specification for high-pressure sodium lamp ballast performance defined by lamp characteristics and upper-lower wattage limits.

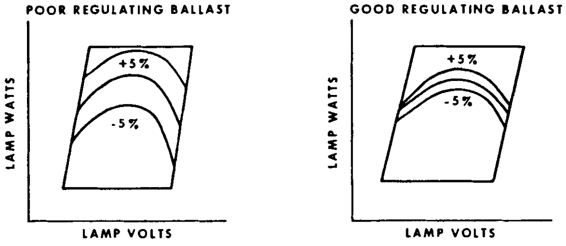


A. THE "IDEAL" HPS BALLAST CHARACTERISTIC. OPERATES LAMP AT NOMINAL WATTS REGARDLESS OF LAMP VOLTAGE.

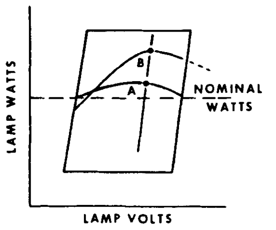
B. GOOD BALLAST CHARACTERISTIC WHICH REGULATES LAMP WATTAGE CHANGES FOR CHANGES IN LAMP VOLTAGE.

C. POOR BALLAST CHARACTERISTIC WHICH PERMITS WIDE LAMP WATTAGE VARIATION AS LAMP VOLTAGE CHANGES.

A. LAMP WATTAGE REGULATION FOR CHANGES IN LAMP VOLTS AS LAMP AGES



B. LAMP WATTAGE REGULATION FOR CHANGES IN LINE VOLTAGE

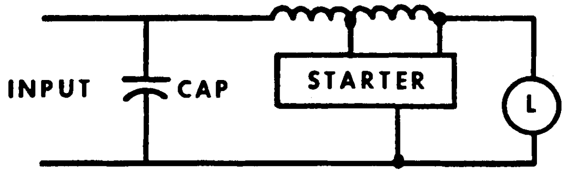


A. GOOD BALLAST CHARACTERISTIC WHICH OPERATES BALLAST CLOSE TO WATTAGE MOST OF LAMP LIFE.

B. POOR BALLAST CHARACTERISTIC WHICH OPERATES BALLAST ABOVE NOMINAL WATTAGE MOST OF LAMP LIFE AND ACCELERATES FAILURE.

C. AVERAGE LAMP WATTAGE THROUGHOUT LAMP LIFE

Figure 35.—Important aspects of ballast characteristic curves.

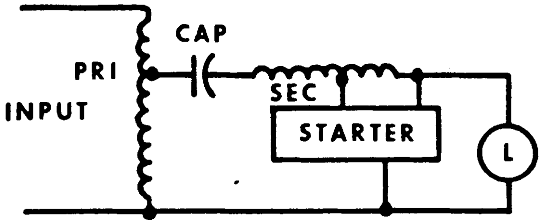


LAG (REACTOR)

Consists of a simple choke; autotransformer may be incorporated if line voltage is insufficient for arc maintenance. Capacitor used for power factor correction. Ballast characteristic curve is flat relative to other types; vertical displacement is large with changes in line voltage.

Advantages:
Inexpensive.
Good lamp wattage regulation as lamp voltage increases throughout lamp life.
Low internal power consumption.

Disadvantages:
Poor lamp regulation with changes in line volts, only ±5 pct voltage tolerable.
Combined regulation for change in line volts and lamp volts is worse than other types.

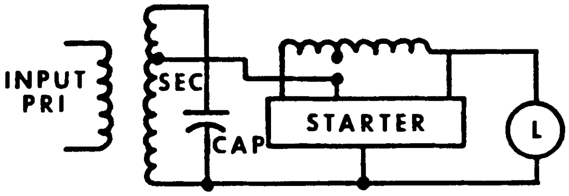


LEAD

Compromise unit that combines performance characteristics of regulator and lag ballasts. Characteristic curve has low vertical shift in the event of line voltage changes but has a higher hump than any other type.

Advantages:
Moderate cost.
Good lamp wattage regulation with changes in line volts, ±10 pct.
Combined regulation for change in line volts and lamp volts is better than lag ballasts but not as good as regulator ballasts.

Disadvantages:
Moderate internal power consumption.
Lamp wattage regulation as lamp voltage increases throughout lamp life is worse than other categories.



REGULATOR (CONSTANT WATTAGE)

Essentially voltage regulator circuit that controls line voltage variations in power provided to lag-type ballast. Characteristic curve is relatively flat. Little vertical displacement of curve with changes in line voltage.

Advantages:
Good lamp wattage regulation as lamp voltage increases throughout lamp life.
Good lamp wattage regulation with changes in line volts, ±10 pct voltage tolerable.
Combined regulation for changes in line volts is best of all 3 types.

Disadvantages:
Expensive.
High internal power consumption.

Figure 36.—High-pressure sodium lamp ballasts.

CHAPTER 4.—AVAILABLE MINE LIGHTING HARDWARE

The objectives of this chapter and appendix B are as follows:

1. Identification of currently available hardware and presentation of major specifications as an information base to assist users in making comparisons.
2. Discussion of the salient design features that impact performance (to be used as a decisionmaking guide in hardware selection).

OVERVIEW

Table 5 identifies and categorizes the mine lighting hardware (area luminaires approved for use at the coal face) currently available in the United States. This categorization is based on the following appropriate major design and application demarcations.

1. Lamp Type.—Systems are available that utilize fluorescent, high-pressure sodium (HPS), incandescent, and tungsten-halogen sources. Systems using mercury vapor (MV) lamps are available, but currently are not being actively marketed because of drop out problems that result from voltage dips in the supply power (see chapter 3).

2. Circuit Designation.—Luminaires, power supplies, and interconnecting wiring utilized at the working face must be designed so that they cannot cause dust ignition or an ignition of a methane-air mixture at concentrations

Table 5.—Categories of available lighting hardware and identification of U.S. manufacturers

Ballast location and type	Lamp		Machine power	Manufacturer
	Shape	Power		
FLUORESCENT SYSTEMS—EXPLOSION PROOF				
Integral:				
Solid state	Tubular	HO-VHO	ac dc	National Mine Service.[1] Mine Safety Appliances.[1] Mine Safety Appliances.
	U-shaped	Standard	ac	National Mine Service.
Core and coil	Tubular	Standard	ac	McJunkin.[1]
Remote:				
Solid state	Tubular	HO-VHO	ac dc Diesel.	McJunkin. Do. National Mine Service. McJunkin.
Core and coil	Tubular	HO-VHO	ac	West Virginia Armature. Joy Manufacturing. National Mine Service. McJunkin. Bacharach Instruments. Crouse Hinds.
FLUORESCENT SYSTEMS—INTRINSICALLY SAFE (POWER LEADS AND LUMINAIRE)				
Remote: Solid state	Tubular	Standard	ac	Service Machine.
FLUORESCENT SYSTEMS—INTRINSICALLY SAFE (POWER LEADS ONLY)				
Integral: Solid state	Tubular	Standard	ac dc Diesel.	Ocenco.[1] Ocenco.
HIGH-PRESSURE SODIUM SYSTEMS—EXPLOSION PROOF				
Remote:				
Solid state	NAp	NAp	dc Diesel.	McJunkin.
Core and coil	NAp	NAp	ac	McJunkin. Mining Controls, Inc. West Virginia Armature. Crouse Hinds.[1]
STANDARD INCANDESCENT SYSTEMS—EXPLOSION PROOF				
NAp NAp	NAp	NAp	ac dc Diesel.	McJunkin. Mining Controls, Inc. West Virginia Armature. Ocenco.
TUNGSTEN-HALOGEN—EXPLOSION PROOF				
NAp NAp	NAp	NAp	ac dc Diesel.	Mining Controls, Inc.

HO-VHO High output, very high output. NAp Not applicable.

[1] Systems have been applied on longwalls. All systems may be applied on mobile face machines.

in the explosive range. One of two design approaches may be utilized to meet this objective:

Explosion-Proof Design.—Power components are housed in an enclosure capable of withstanding internal explosions without damage to the enclosure or discharge of flame (30 CFR 26.2(h)).

Intrinsically Safe (IS) Design.—A fixture, a combination of parts, or an electrical circuit are designed such that they will not cause ignition of flammable methane-air mixtures in any normal operation, during an intended manipulation, or when accidentally broken, if properly installed and powered by a voltage that does not vary excessively from the nominal rating (30 CFR 26.2(f)).

Certain fluorescent lighting systems are rated IS. The two manufacturers of IS systems—Ocenco, Inc., and Service Machine Co.—have very different designs to meet the IS criteria. The Ocenco system power supply produces low voltage (12 V) dc power with voltage and current monitoring and limiting circuits to produce failsafe intrinsically safe power to drive the luminaires. A solid-state inverter ballast integral to the luminaire converts the 12-V dc power to a high-frequency lamp drive power. The Service Machine power supply produces a very high-frequency, medium-voltage power that is intrinsically safe and drives the lamps directly. Hence, only the cabling is intrinsically safe on the Ocenco system, whereas, both the cabling and luminaires are intrinsically safe on the Service Machine system.

3. Ballast Location.—Lamp ballasts may be located integral to the luminaire or remotely in a separate explosion-proof enclosure. Intregally ballasted luminaires were initially developed for application on longwalls, primarily to facilitate wiring. Relative merits of the two designs are discussed in detail in a subsequent section.

4. Ballast Type.—Ballasts to condition power for lamp starting and drive may utilize either conventional core-and-coil or solid-state ballast technology. The major reasons for application of solid-state ballasts in mine lighting are (1) the reduced size of these ballasts and (2) the ability of solid-state ballasts to convert any source power (ac or dc) to a suitable lamp drive power. Because of one or both of these characteristics, solid-state ballasts have been widely applied where standard ac power is not available (i.e., the IS systems and for dc and diesel machines) and on integrally ballasted systems. Solid-state ballasts drive lamps at high frequency, hence, yielding improved efficacy for the arc-discharge lamps. It should be noted that application of solid-state ballasts on dc machines generally requires additional voltage regulation and transient suppression circuitry.

5. Lamp Shape.—Lamp shape is an important distinction for fluorescent luminaires, affecting luminaire profile and photometrics. Most fixtures use standard T-shaped lamps of various lengths, and wattages, which are housed in cylindrical luminaries. A National Mine Service fixture utilizes small, U-shaped lamps that enable a relatively flat profile and incorporation of a unique lamp shielding technique in the fixture lens (see appendix B).

6. Lamp Power.—Lamp drive power is another important distinction for fluorescent luminaires. "Standard" 1-in-diam T-shaped lamps are driven at 400 mA, consuming about 1 W per inch of length. For the purposes of increasing lumen output from a given luminaire size; lamps that operate at higher current have been developed. Lamps that are designed to operate at 800 mA are designated high output (HO), produce approximately 40 pct more lumens than 400 mA lamps, and consume about 50 pct more power. Lamps that operate at 1,500 mA are designated very high output or super high output (VHO or SHO), produce about 100 pct more lumens than 400-mA lamps, and consume about 200 pct more power. It is evident that this increased light output is achieved at the expense of a loss in efficacy and an increase in luminaire surface intensity. Because of these disadvantages it is important that a need for the additional light output exist before applying these lamps.

7. Machine Power.—All mine lamps are driven on alternating current, with the exception of incandescent and tungsten-halogen light sources, which can use either ac or dc power. (There has been some experimentation with dc drive of fluorescent and MV lamps, but these systems are not commercially available.) For arc-discharge systems applied on dc and diesel machines, lighting power supplies are constructed with provision for producing alternating current for powering the lamps. On dc machines, most systems rely on solid-state inverter ballasts to obtain the alternating current although additional voltage dropping, voltage regulating, and transient suppression hardware is typically provided. One IS system inverts the power to high frequency ac and then conditions it with circuitry similar to that utilized in its ac power supply. Systems available for diesel machines use generators or alternators to generate electrical power and, respectively, are coupled with dc or ac power supplies. Appendix B provides a functional description of the various power condition systems available.

Readers are referred to appendix B for detailed information and photographs of area illumination hardware approved for application at the coal mine face.

HARDWARE EVALUATION

Selection of appropriate hardware is a very important aspect of successful illumination system design and implementation. As an aid to selection, this section delineates major hardware design features that have significant impact on field performance. Note that no particular luminaire or power conditioning system is optimum regarding all aspects of performance. A decision to select particular components requires careful consideration of the performance tradeoffs between the alternative candidates. The characteristics of the application must be considered to establish the relative importance of these tradeoffs. For example, luminaire durability may be much more important on one application than on another. Moreover, concurrent consideration should also be made of the feasibility and cost of altering specifications for the application or modifying the hardware to compensate for particular weaknesses, while exploiting other strengths (e.g., adding supplementary guards to protect a relatively fragile luminaire with other positive performance aspects such as high lumen output, easy servicing, etc.).

The following is an identification and discussion of salient features that have been demonstrated to have significant impact with respect to four major performance criteria—ruggedness and durability, electrical reliability, system servicing, and illumination performance. In addition, a miscellaneous category addresses other important performance aspects. When appropriate, the discussion identifies application characteristics that make consideration of the feature especially important.

Ruggedness and Durability

With existing machine designs and illumination hardware, a degree of exposure of illumination system components to the hostile mine environment is necessary. Because of this, the implementation of lighting systems on face machines has, at some mines, resulted in a significant increase in maintenance load and costs. The importance of system ruggedness varies greatly from one application to another with mine conditions being a major determinant. Conditions such as a high ratio of machine-to-entry dimensions, undulating bottom, and poor roof can be very destructive to lighting systems. The following are major features that determine the ruggedness of the hardware itself. These features are important, but they should not be the sole basis for hardware selection. Other performance aspects are also very important. Moreover, in some applications, the layout of system components to avoid excessive exposure and the provision of supplementary protective structure has much more impact on system durability than the inherent strength of the hardware.

1. Luminaire Cross-Section.—Minimized luminaire exposure to contact-impact forces frequently encountered on machine-mounted installations is generally easier to achieve with the low-profile fixtures (e.g., fluorescent luminaires). This is true because (1) low-profile fixtures offer greater clearance when they are exterior mounted, (2) locating the fixtures within the confines and protection of existing machine structure is possible in some instances, and (3) machine modifications to recess the fixtures are generally more feasible. Exposure of high-profile, exterior mounted, incandescent or high-intensity discharge (HID) luminaires can be a particular problem on machines where roof height exceeds machine frame height by slightly more than 12 in. On such applications, roof lighting is required and this would typically be accomplished by fixtures mounted on the machine top-deck. Clearance above a typical 8-in HID or incandescent luminaire would be minimal and potential for roofing would be high, especially on undulating roadways.

2. Luminaire Length.—The relatively long length of certain fluorescent fixtures is a disadvantage in many applications because (1) when mounted in the horizontal plane, exposure to impact is relatively high; (2) a long span makes construction of a strong protective cage difficult, more and heavier cage members must be utilized which, in turn, reduce lumen output; (3) long length makes recessing and/or positioning the fixture within the confines of existing machine structure more difficult. Short fluorescent fixtures, less than 14 in are available, and they offset many of these disadvantages. Moreover, it is possible (and for photometric purposes, often desirable) to mount these luminaires in a vertical position on the sides of the machine where exposure to many impact hazards would be reduced relative to horizontal mounting on the machine top-deck or sides. High-pressure sodium (HPS) and incandescent luminaires are also short enough for vertical mounting on machine sides, however, construction of supplemental protective guards is frequently desirable in this case because of the high profile of these fixtures.

3. Luminaire Housing Construction.—Housings of incandescent and HID luminaires are generally stronger than the fluorescent luminaire housings. For this reason, luminaires in this category are generally regarded as more rugged. However, it should be noted that fixture exposure is greater in many applications. Even though the housings are durable, they are exposed and glass lens breakage may occur frequently, necessitating replacement of the luminaire. Also, note that dependent on size, materials, and design of housing members, differences in housing strength exist between alternative luminaires within the same category. Finally, the extremely high housing strength of certain luminaires in this category can be a problem when the fixtures are subject to impact in such a manner that they might be driven into the machine body. If machine covers are flimsy, forces may be transmitted to underlying components causing damage more sigificant than the loss of a luminaire.

4. Protective Cage Designs.—Available luminaire guards and protective cages vary widely in their ability to protect luminaires from damage from the common contact and impact forces experienced by machine-mounted lighting systems. Indeed, some guards serve little more than a cosmetic purpose. The following points should be considered when evaluating cage designs:

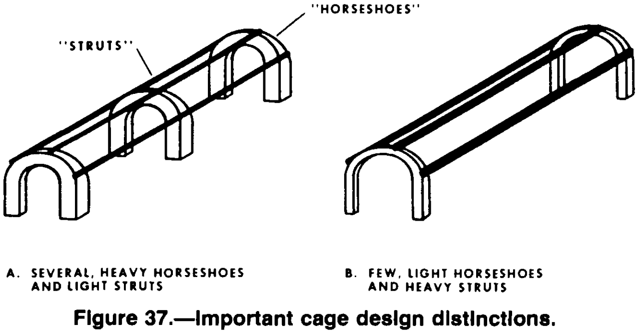
a. Mechanical isolation (weak mechanical interconnection) between the protective cage and the lamp housing is a desirable feature because it minimizes stress transfer between the cage and lamp housing. This can significantly reduce the degree of luminaire damage when impacted.

b. Considering generalized guard designs (fig. 37), those with several, heavy "horseshoes" and light struts are preferable to those with few, light horseshoes and heavy struts. This is true because the horseshoes are more effective in breaking impacts than the struts are and when horseshoes are used in greater numbers the span of the struts is reduced, which increases their protective capability. It is also important to note that the struts have greater photometric impact than the horseshoes, especially if they are large in diameter.

c. On some available cages, the longitudinal struts are tacked to the underside of the horseshoes rather than on the outside. These welds are easily broken and the bars can readily be pushed into the luminaire.

d. Some manufacturers offer heavy-duty cages as options with their luminaires. Photometric impact must be assessed when utilizing these cages, but their addition has proven feasible and beneficial in many cases without requiring the use of additional luminaires to meet lighting requirements.

5. Packing Glands.—Maintenance of the structural integrity of packing glands is of great importance to mine operators because damage can create a hazardous situation and void the permissibility of the lighting system. Various design features impact gland durability and the



A. SEVERAL, HEAVY HORSESHOES AND LIGHT STRUTS

B. FEW, LIGHT HORSESHOES AND HEAVY STRUTS

Figure 37.—Important cage design distinctions.

durability of the cables and associated conduit feeding the luminaires and power supply enclosures. They include the following:

a. Tubing Versus Clamp-Style Glands (see figure 38).—The following points are relevant when comparing these gland styles:

(1) Clamp-style glands offer better strain relief than most tubing designs. This should reduce the frequency of incidents of pulling cable out of the gland opening, which voids the permissibility of the gland. This type of failure is a particular problem on certain longwall installations, especially chock faces.

(2) Clamp-style glands offer greater impact resistance and are more easily dented than most tubing-style glands.

(3) One disadvantage of clamp-style glands is that they currently are only available in 90° orientation. If cables must be routed tightly away from the gland exit, the clamp has a tendency to damage conduit.

b. Gland Angle.—Some lighting suppliers offer options in gland orientation angles (e.g., 45°, 90°, straight), whereas others do not. Appropriate gland angle for the luminaire location is desirable for the following reasons.

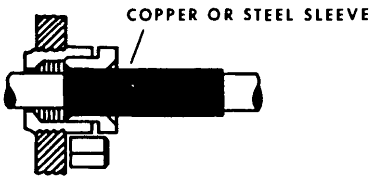
(1) Proper gland angle permits good routing of cables away from the luminaire. This can greatly reduce cable exposure and stress damage to cable or conduit if the cable is routed away from the gland at a sharp angle (fig. 39.)

(2) On certain explosion-proof enclosures, spacing of the gland entrances is such that if 90° threaded glands are used, it is necessary to remove one or more glands to gain access to the one desired because of lack of clearance between the adjacent glands.

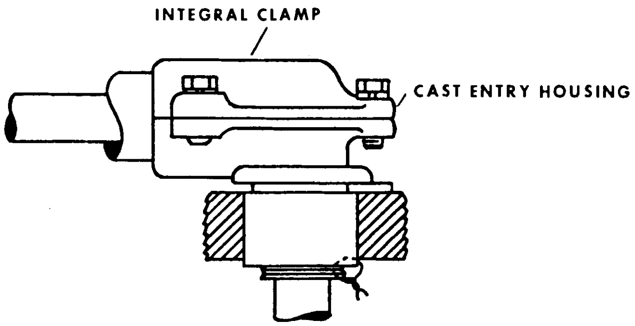
c. Number of Glands in System.—Obviously, the greater the number of glands used in a system, the greater the potential for gland failure and/or damage and for increased maintenance. Therefore, in selecting or designing a lighting system the number of glands utilized should be an important consideration. For example, IS systems have a reduced number of packing glands relative to explosion-proof systems for a particular application.

6. Lens (Polycarbonate-Lexan).—Polycarbonate and lexan lens material used on fluorescent luminaires has excellent impact resistance. However, there is some concern that this strength is reduced through aging. Laboratory tests have shown no significant heat-induced aging of polycarbonate after several thousand burn hours on luminaires with heat shields above the lamp cathodes (a feature of all currently approved luminaires). However, the lens in this test were kept clean, and the effect of dirt and grease is not known. A good lens cleaning program is thus recommended for this reason, as well as for minimizing the luminaire's lumen depreciation. Those polycarbonate lens with threaded ends might be prone to breaking more readily, failing at the weak area near the junction of the threads and the solid tube.

It is important that polycarbonate and lexan lens be protected from the heat of welding torches and from weld splatter. Also, solvents containing hydrocarbons can react with and damage the lens.



A. TUBING STYLE



B. CLAMP STYLE

Figure 38.—Tubing versus clamp-style packing glands.

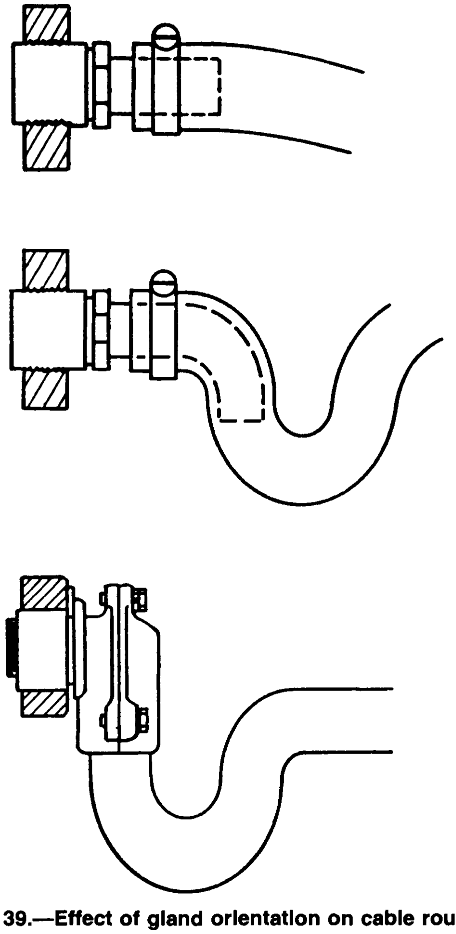


Figure 39.—Effect of gland orientation on cable routing.

7. Lens (Glass).—Glass lens breakage on HID and incandescent area luminaires is a common failure when these fixtures are mounted in exposed locations. It should be noted that when these lens fail, fixtures must be returned to the factory for replacement. Flame path criteria must be met in reinstallation of the lens; accordingly, the Mine Safety and Health Administration (MSHA) requires that the task be performed by an approved vendor.

8. Cabling.—Systems with dual-glanded luminaires permit chaining of luminaires (i.e., feed-through wiring) off a single power lead. This may show an advantage on some longwall applications over single-glanded luminaires that require a separate lead from the power supply box to each luminaire. Dual-glanded systems require less cable, which reduces cable exposure and in turn reduces cable failures on longwalls that experience problems with roof rock falling between supports or with cables getting snagged on rock and pulled behind the supports.

9. Materials.—The following materials-related problems have been reported in the field:

a. Aluminum fixtures show the following disadvantages relative to steel, ductile iron, and brass:

(1) They are more subject to breakage when impacted. A particular problem has been experienced on headlights with aluminum mounting "feet" or "tabs." For this reason one available fixture features bolted on tabs that can be replaced and mounted in alternative positions.

(2) Threaded aluminum components are prone to gall from rockdust.

(3) Salts found in some mines will attack aluminum components.

b. Threads on brass components are easily stripped. Brass housings are more easily bent than steel.

c. Steel lock screws on fixtures are prone to corrode in place after a period of time.

Electrical Reliability

Achievement of high electrical reliability levels for illumination systems has been difficult at many mines, with excessive rate of lamp failure the most widespread problem. The attainment of high reliability levels should be given much attention. Even in cases where parts and labor costs for making repairs are low, lighting system failures can be a significant drain on machine availability, with resultant associated high lost-production costs. The most important factor to consider is the compatibility of the system with the available power source on the particular machine application. Mine power systems are subject to wide deviation in supply voltage from nominal (both high and low), because of changes in the power system load and excessive voltage transients.

Great care should be taken to establish the supply voltage characteristics for a given application and to select hardware capable of accommodating them. Selecting hardware based on nominal voltage specifications can result in serious error and, should, therefore, be based on site-specific measurements that are easily accomplished for establishing supply voltage and its variations. However, transient measurement is difficult to make. In some instances, particularly certain dc applications, a trial installation, with close monitoring of rate and cause of electrical failure, may be a desirable approach for determining the electrical reliability of the hardware. Results of these trials should make it possible to install power conditioning equipment in conjunction with the hardware supplier to achieve an acceptable level of reliability.

Systems for dc Application.—Reports on the electrical reliability of illumination systems applied on dc face machines have been very mixed, with both reliable and unreliable performance reports for the various system designs available for this application. The limited field information available on the performance of dc systems prohibits a thorough discussion of the anticipated performance of the various design features of the candidate hardware. The following points, however, should be of some aid in making selection decisions.

1. Consideration of Power Parameters.—Power parameters vary greatly from one dc application to another and have great impact on the reliability exhibited by a particular system design. "Normal" voltage available to the lighting power supply may differ significantly from the machine nominal voltage. Even though voltages on dc machines are typically specified in ranges, e.g., 250 to 300 V dc or 500 to 600 V dc, it is not unusual for the effect of line load variations to produce sustained voltages up to 33 pct less than the lower range value or 25 pct above the upper range value. Moreover, ac ripple may produce peak voltages 25 pct in excess of the upper range value. Obviously, knowledge of the typical operating range for the particular machine in question would be of value in evaluating and specifying hardware, because available dc hardware designs vary significantly in their ability to regulate voltage and in the effect of voltage variation on system function. Moreover, minor design modifications can be made by the hardware supplier to improve system performance on some lighting systems on the basis of an accurately specified normal operating voltage level and the upper and lower values of the voltage variations.

The second major power consideration is line transients, which can be caused by any of the following:

a. Switching of large transformers and motors on the ac distribution line that feeds the dc rectifier on a section load center. These transients may produce, on the secondary side of the rectifier, very high voltage peaks that are generally short in duration. The problem is likely to be worse on systems employing vacuum switches on the ac line.

b. Switching and arcing on the dc line itself can produce significant transients. These tend to be of lower peak voltage than those orginating on the ac line but are of much longer duration and are also bipolar (important when protecting solid-state circuits).

c. Because line inductance tends to dissipate transients from other sources, the most serious transients can be those that originate from switching and arcing on the particular machine application itself.

Field survey data show a significant difference in performance between systems applied on dc machines where the power originates at load-center-based rectifiers fed from ac primary distribution, and those where mine distribution is dc (trolley line or dc cable). In the former case, good electrical reliability was frequently achieved on both arc discharge and incandescant systems. In the latter case, problems were much more severe, no doubt attributable to the poorer voltage regulation and extreme transient conditions. It is recommended that knowledge of the character of the application (field measurements and circuit analysis) be obtained as a basis for dc hardware selection decisions.

2. Incandescent Versus Arc Discharge Systems.—When comparing incandescent to arc discharge (fluorescent and HID) systems for operation on dc power the following points are relevant:

Incandescents can operate directly on dc power requiring minimal supplementary power conditioning hardware. Generally, simple, rugged voltage drop resistors comprise the circuit in addition to the lamps. Alternate circuits for dc application of headlamps are shown in figure 40.

Arc discharge systems (fluorescent and HID) convert the dc to some form of ac to drive the lamps. This requires use of inverters and supplementary circuit protective devices to prevent damage from transients and poor voltage regulation. Extreme voltage fluctuations, however, can damage the protective components as well as the other circuit constituents.

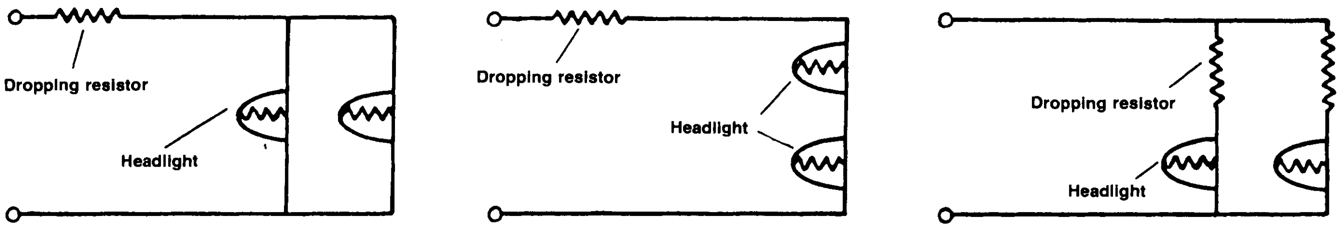
Operationally, incandescent lamps are less affected by voltage fluctuations than other lamps. Temporary overvoltages and undervoltages, including transients, will not extinguish the lamps and have little effect on the lamp characteristics including minimal life reduction. Voltage dips will extinguish gas discharge lamps, with considerable restart time required for HID's (HPS lamps restart quicker than MV lamps and time can be further reduced with an instant restrike starting aid). Moreover, transient voltage spikes can damage the arc tube of HID lamps, greatly reducing lamp life.

Because of the inherent advantages, incandescent systems have seen wide application on dc equipment. On applications where voltage fluctuation problems are extreme, incandescent systems will probably yield the best reliability. When implementing these systems, it is important that drop resistors be sized for the actual operating voltage rather than nominal voltage. Undersized resistors will overdrive the lamp, greatly reducing its life. Lumen output from an incandescent luminaire is, of course, less than a gas discharge luminaire. This limits application in higher seam heights.

3. Comparison of Gas Discharge Lamp Alternatives.—Available dc power conditioning systems for use with gas discharge lamps vary significantly in provision to regulate supply voltage and to protect components from voltage transients (see appendix B for a description of these systems). It is important to consider these features in conjunction with the application parameters when assessing hardware suitability.

Lamp Life.—Costs incurred because of reduced lamp life can be very significant in mining applications, and realization of long average lamp service life should be given great consideration when making hardware selection decisions. Although life differential between alternative lamp types is a performance characteristic that might be highly touted by a hardware supplier, it is important to recognize that these rated values are frequently based on laboratory tests rather than field measured values. Mine application conditions are harsh and statistics have shown that (1) rated service life is seldom achieved on mine application, frequently not even approached, and (2) rated service life is also an invalid basis for making relative comparisons between alternative lamps. Determination of the best lamp with respect to life performance requires careful analysis of the characteristics of the application including the approach that will be taken in maintaining the system. The reader is referred to chapter 6 for a detailed comparison of lamp types and a suggested approach for lamp selection, installation, and maintenance.

Comparison of Core-and-Coil Ballasts.—Standard core-and-coil ballasts have a long expected life—approximately 6 yr with a 24-h/d duty cycle. Frequently, this life is not realized in mine application. Poor heat dissipation environments, shorting of the power leads, overvoltage operation, and protracted operation with failed or near-failed lamps are major factors contributing to ballast overheating and reduced ballast life. Ballast designs differ in their tolerance of these conditions. Moreover, concerning overvoltage and undervoltage operation, ballasts differ in their ability to regulate lamp voltage and current, and



PARALLEL

Advantages:

Easy to wire, only 3 leads required.

Isolation of failed lamp simple if 1 lamp fails.

Second lamp remains in operation if 1 lamp fails.

Disadvantages:

Life of remaining lamp shortened when 1 lamp fails unless it is replaced immediately.

SERIES

Advantages:

Easy to wire, only 3 leads required.

Life of remaining lamp is not shortened when 1 lamp fails.

Disadvantages:

Isolation of failed lamp difficult if 1 lamp fails (neon indicator can reduce problem.)

Second lamp does not remain in operation if 1 lamp fails.

SERIES-PARALLEL

Advantages:

Isolation of failed lamp simple if 1 lamp fails.

Second lamp remains in operation if 1 lamp fails.

Life of remaining lamp not shortened if 1 lamp fails.

Disadvantages:

More difficult to install; 5 or 6 leads required.

Figure 40.—Alternative wiring configurations for dc application of incandescent headlamp pairs.

this affects the service life realized by the lamps. Specific features of note include:

Dual-lamp parallel fluorescent ballasts are available and have been applied because they can simplify troubleshooting procedures relative to series dual-lamp ballasts. Field experience has not been favorable, however, because they tend to frequently fail from overheating. Leads shorting was cited as the cause of most overheating incidents.

As previously noted, widely variable line voltage is a circumstance found in many mine lighting applications. Compromising performance for cost, many mine lighting hardware suppliers do not provide the best available ballast for regulating line voltage variation. Chapter 3 identified major ballast designs available for mine lamps and discussed their performance tradeoffs. If the application warrants concern, it is recommended that users consult hardware suppliers for information on the design of the ballast they supply. Since many ballasts are off-the-shelf items, substitution of better performance ballasts may be possible, dependent on their availability.

As noted in chapter 3, by using more material (i.e., larger diameter conductors for coils) ballast power consumption and heat production can be reduced. In many mine applications this feature is desirable because the heat dissipation character of the environment where the ballasts are mounted is poor or overvoltage conditions might exist. Ballast manufacturers have given many names to ballasts designed using this principle including "premium," "low-heat," and "energy-saver" ballasts.

Multitap ballasts available from some mine lighting hardware suppliers may offer improved performance in applications where line voltage deviates from nominal but tends to be consistently high or low.

An integral instead of a remote ballast approach may yield improved ballast performance in some installations. This is particularly true for systems requiring a large number of luminaires (and many ballasts), and where supply power is poorly regulated.

Heat Dissipation Character.—As noted, overheating of electrical components, especially ballasts, can be a major problem in mine lighting. The heat dissipation character of a candidate power supply should be checked. Factors to review include the contact area of heat-producing components with the enclosure of heat-sinking materials mounted in the enclosure and the component packaging arrangement. Problems have been experienced with systems using several ballasts tightly stacked. An increase in temperature of just a few degrees can greatly reduce ballast life. Chapter 6 discusses this problem in greater detail.

Transformers.—The following are two important criteria for evaluation of the auxiliary lighting system power transformers:

1. High-Low Voltage Taps.—Operating voltage at the machine frequently deviates from nominal but lighting system components have little tolerance for deviation from specification. Transformers with high-low taps allow compensation on the basis of measured actual values and can improve system performance.
2. Kilovolt-Ampere Capacity.—On systems where additional headlights are added beyond MSHA statement of test and evaluation requirements, it is necessary to check that transformer capacity is adequate. Instances where this was overlooked and capacity was exceeded have been reported quite frequently.

Line Losses.—Voltage drop attributable to line losses can be a problem on longwall installations. The resulting low voltage can cause lamps to frequently extinguish and significantly shorten the service life of fluorescent lamps. Design features that minimize line losses include the following:

Use of conductors of sufficient size to keep voltage drops low.

Reduced number of lamps in a single line or even use of an individual line to each lamp (this will increase required number of power supply and/or junction boxes).

Use of more than one power distribution line along the face.

Use of autotransformers as voltage boosts.

Line loss problems can usually be avoided through careful specification of the system configuration.

System Servicing

Regulations require that lighting systems be maintained in fully operable condition at all times during production operations. Occasionally, this might force shutdown of a machine to make repairs on the lighting system, and the associated lost-production costs can be very high. Because of these costs and the high cost of maintenance labor, it is very important that lighting systems be implemented so that they are quickly and easily serviced. This requires that fault diagnostic procedures be few and uncomplicated and that repairs can be made quickly. Available hardware varies greatly concerning these performance aspects, and the major determinants of these performance criteria are outlined in the following sections.

Explosion-Proof Versus Intrinsically Safe Systems.—Regulations require that persons performing maintenance work on explosion-proof systems be certified electricians. This is not a requirement for working on intrinsically safe systems or any part of a lighting circuit that is intrinsically safe. Because certified electricians are scarce at many mines and are usually involved with projects of higher priority, the implementation of intrinsically safe systems might facilitate conduct of lighting system maintenance on certain installations, particularly longwalls.

Housing of Power Conditioning Components.—The number and type of power conditioning components required for a lighting system varies depending on the size of the system and the available machine power. Explosion-proof enclosures offered by the lighting hardware suppliers to house these components should be reviewed with respect to (1) size compatibility with the components to be housed, and (2) the packaging arrangement of components within the enclosures. Many hardware suppliers offer a limited number of different-sized explosion-proof enclosures to house their power conditioning equipment. Size should be adequate to house the required components in an acceptable packaging arrangement but not so large that locating the box on the machine is a problem, forcing a compromise between protection and accessibility. Some manufacturers have required the use of two boxes to house the components for certain systems. This can increase accessibility problems for certain diagnostic tests in the event of electrical failures. Component packaging arrangements greatly affect the ease of making diagnostic tests and component exchanges. Criteria for review include component spacing (also affects temperature buildup), ballast stacking arrangement, and connection of the components to the enclosure; a systematic, efficient, and easy to trace wiring arrangement with a complementary terminal strip layout; and the use of plug connections between components.

Lamp Change Difficulty.—Luminaires vary greatly in the degree of difficulty required to make lamp changes. The importance of this factor depends on whether failed lamps are changed at the face or whether the entire luminaire is replaced in an exchange maintenance program. In the former case, lamp change procedures should be reviewed very carefully. Points to check for include the following:

What is necessary for lamp access? Fixtures with threaded or slip-fit endcaps are preferable over those where a bolt-attached end plate must be removed. Headlight designs vary significantly in requirements for accessing the lamp. Lamp changing is facilitated by designs where removal of the lens retainer exposes the entire lamp.

How is the lamp retained? This is significant when comparing fluorescent luminaires. Cartridge-type lamp holders with plug-type connection to the lamp power are generally easy to change, although pin alignment can be difficult on some designs. Those that use the ground wire to hold the fluorescent lamp-socket assembly together can be very difficult to work with underground.

Incandescent Versus Arc-Discharge Systems.—The circuit simplicity of incandescent systems makes them very easy to troubleshoot. Ballast failure is not a possibility and, if wired in parallel, all common system failures can be isolated or narrowed between a few alternatives on the basis of which lamps are burning. Neon bad-lamp indicators can be used to facilitate fault isolation of series wired lamps.

As a general rule, because of ballast and circuit configurations, failures on gas discharge systems tend to be more ambiguous and are more difficult to isolate. Also, off-standard voltage levels can confuse electricians who have had little experience with this type of equipment.

Advantages of Modular Construction.—Modular construction, the isolation of electrical components into functional groupings generally with convenient plug-in connection to the circuit, greatly facilitates fault isolation. This is true because of the following:

1. Circuit redundancy is an easily used advantage. Leads can be switched to an existing duplicate modular unit to test for a suspect lead.
2. New units can readily be substituted for suspected faulty ones to test the status of the suspect unit.
3. Detailed fault isolation within a modular unit is unnecessary, or at least unnecessary to perform at the face. Replacing the unit reduces the number of causes that must be investigated before identifying the cause of a failure and implementing a remedy. This simplifies and minimizes troubleshooting. It is possible that obvious manifestations of a failure, e.g., which light(s) will not operate, can make deduction of the cause of the failure self-evident without the conduct of tests.

Specific instances where modular construction resulted in significant benefits in fault isolation include the following:

Integrally Ballasted Luminaires.—These fixtures are generally equipped with connectors that in effect combine the lamp and ballast into a single functional unit that is readily exchanged. Faults are more easily identified and repaired since the ballast is dedicated to a single lamp and isolation within the group is unnecessary at the face.

Modular Construction of Certain Electronic Intrinsically Safe Systems.—On certain systems, circuits are built on functionally distinct plug-in circuit cards. Failure manifestations usually make fault isolation simple and testing is easily achieved by substituting duplicate cards.

Use of Explosion-Proof Connectors To Isolate Units. —Specification of explosion-proof connectors to isolate units (usually power supply boxes) is generally optional and left to user discretion. These connectors can reduce downtime for making system repairs in some instances. Generally, testing would proceed to check components most likely at fault. If these are not found to be damaged, more detailed isolation is not performed. Rather, the entire unit is exchanged with a new one. This specification is more practical and useful on some systems than others.

Series-Wired, Dual-Lamp, Core-and-Coil Ballasts. —Cable faults, lamp failure, and ballast overheating are common failures on some system installations. With dual-lamp ballasts that drive the lamps in series, any one of these failures can cause the same manifestation—the lamps on the circuit do not light. Troubleshooting to isolate the particular fault among the possibilities may require a relatively extensive series of tests that might require access to the power supply enclosure. Time requirements for fault isolation are excessive relative to fault isolation of single-lamp ballasts. Dual-lamp ballasts that drive the lamps in parallel are available and would simplify fault isolation. However, field experience has shown them to be unreliable in mining application because they overheat quickly when leads are shorted.

Connectors and Slip-Fit Glands.—Systems employing connectors facilitate diagnosis of cable faults because of easy access to the leads. This is particularly important on longwalls where cable faults may be common and procedures for localization may be tedious. Both connectors and slip-fit glands greatly facilitate component exchange.

Accommodations for Connecting Power Leads.—Available luminaire designs vary greatly in requirements for connecting power leads. The following points are relevant for evaluation from an installation-servicing aspect.

1. Adequate Space.—Spatial requirements for connection of six-lead luminaires in particular are large and some designs require special routing of the leads to make the connections.
2. Terminal Strips and Spring-Loaded Connections. —Luminaires with these devices for making connections are easier to install and exchange than those with wire-nut connections. Terminal strips also facilitate testing for diagnosis of cable faults.

Illumination Performance

Chapter 3 was devoted to a discussion of the intrinsic performance differences of the various lamps used in coal mine face lighting systems. Although these differences are significant, the major determinant of the success of a system from an illumination viewpoint lies more in the careful and creative deployment of the hardware than in the inherent performance differences among the available luminaires.

Summary of Lamp Performance Differences.—Many important differences in lamp performance have been pointed out previously with respect to electrical reliability criteria. Table 6 summarizes lamp performance differences that are related to illumination system performance.

Luminaire Photometrics.—The suitability of a luminaire's photometric profile (as might be expressed by an isofootcandle curve) is very dependent on the designer's objective in a particular application. Two general points, however, are of significance:

1. In low and medium seam heights, lumen distribution requirements are such that it usually is not possible to decrease the number of luminaires in the system by using luminaires with higher lumen output. Indeed, high-output, small-size luminaires may decrease the uniformity of illumination levels, which might be undesirable.
2. Most mine luminaires emit the greater portion of their lumen output perpendicular to the lamp axis as opposed to the parallel direction. Since in illumination system design there is usually a need for greater light output in the horizontal plane than the vertical plane (room length and width are usually greater than room height) it is advantageous to mount luminaires vertically. Short fixtures facilitate such utilization. Manufacturers can usually provide photometric data on their fixtures and this information can be of great value in the initial stages of the design or design modification process. MSHA's Beckley (WV) Electrical Testing Center may also be a source of such data.

Miscellaneous

Luminaire Repair and Salvage.—Damaged luminaires are generally salvagable items. In addition to consideration of the initial cost of the fixture and its inherent durability, one should also consider typical salvage-repair costs. These vary widely from one luminaire to another depending on typical extent of damage, design, materials, and manufacturer's markup for replacement parts. It is recommended that purchasing agents survey the hardware suppliers who offer rebuild services and the service companies that repair mine lighting hardware to obtain typical cost figures for reconditioning luminaires.

Important Operational Aspects.—It is important that illumination systems remain operational at all times. Systems with luminaires that frequently stop functioning (drop out) can create a very annoying and possibly hazardous circumstance. The following points are significant in this regard:

HID lamps are most subject to dropping out when voltage dips. MV lamps will not restart for some period of time (4-5 min). HPS lamps will restart quicker (90 s) and instant restart can be achieved if a special lamp starter is utilized or solid-state ballasts are utilized. It is recommended that these starting aids be specified by the user on conventionally ballasted systems.

Most systems transform machine power to 120 V ac to operate the ballasts. Higher voltage ballasts are available for direct connection to machine power. However, this reduces isolation on the lighting circuit and creates potential for lighting system faults to trip machine power—an undesirable event. Use of high voltage ballasts should, therefore, be avoided. Excessive line losses can create operational problems with fluorescent systems on longwalls. As mentioned previously, careful system specification can avoid this problem.

Hardware Supplier Services.—The services provided by mine lighting hardware suppliers can be as important in many applications as the quality of the hardware they provide. A supplier under consideration should be questioned concerning the following services:

Availability of field representatives to supervise initial or special installations.

Availability of installation, maintenance, and troubleshooting training courses or seminars with adequate documentation of installation and maintenance procedures.

Table 6.—Summary of illumination performance differences dependent on lamp types utilized in a luminaire

Performance aspect	Incandescent	Tungsten-halogen	Fluorescent			High-intensity discharge	
			Standard	High output	VHO-SHO	HPS	MV
Efficacy	Low	Low, better than incandescent	High	High	Moderate	Very high	High.
Lumen output versus size.	Moderate	High	Low	Moderate	More than high high output.	do	Very high.
Surface intensity of bare lamp.	High	Very high	Low	do.	Moderate, high	do	Do.
Color rendition.	Excellent	Excellent	Good	Good	Good	Usually acceptable.	Poor.
Flicker; potential for stroboscopic effect.	Not a problem	Not a problem.	(1)	(1)	(1)	(2)	(2)
Lamp extinction when voltage dips.	do	do	Possible, not likely	Possible, not likely.	Possible, not likely.	(3)	(3)
Lumen depreciation over rated service life.	Low	Low, less than incandescent.	Moderate	Moderate.[4]	Moderate.[4]	Very low	High, over very long life.

HPS High-pressure sodium. MV Mercury vapor. VHO-SHO Very high output, super high output.

[1] Unlikely to be a problem except near end of lamp life. Proper maintenance important.

[2] May be a problem. Can be avoided through careful design.

[3] A significant problem, especially with MV lamps, which take a long time to restrike.

[4] Much depreciation occurs in early part of lamp life.

Assistance in causal diagnosis of frequent electrical failures. Willingness to modify standard power conditioning system to accommodate specific mine requirements.

Assistance in illumination system design modification, including filing papers for STE extensions.

Assistance in filing STE applications for longwall lighting systems.

Proximity of distributors and service representatives.

Availability of hardware rebuild-exchange programs.

Location of other authorized repair service vendors.

CHAPTER 5.—DESIGN AND EVALUATION OF COAL MINE ILLUMINATION SYSTEMS

The design of underground coal mine illumination systems that provide improved visibility and safety, meet the minimum specifications of Federal regulations, and are well accepted by the mine worker and mine operator is a difficult task requiring great care and effort. As outlined in chapter 1 of IC 9073, consideration of numerous interrelated factors such as severe environment, extremely low reflectance of coal, occurrence of objectionable glare problems, is required.

A well-designed illumination system can provide important benefits to the machine supplier and user including

Improved safety. Hazards, especially in the mine workers' peripheral field of vision, can be more readily detected.

Improved overall areal perspective and task visibility, which could assist in improving task performance and, ultimately, productivity by improving both the quality and speed of vision.

Conversely, a poorly designed system can cause significant problems such as

Excessive glare which may result in operator visual discomfort or visibility diminished significantly from what could be achieved.

Excessively increased machine maintenance and resulting increased production costs.

The purpose of this chapter is to present guidelines for the design and evaluation of illumination systems, to present methods to address the various types of problems encountered, and to provide design examples. Only the design of equipment-mounted illumination systems is discussed. Workplaces can also be illuminated by luminaires not mounted on the machinery. These systems, called area illumination systems, have to date proved to be an impractical approach for illuminating underground coal mines. Their major problems are that they must be moved separately as the workplace advances and added electrical cables further encumber the already crowded workplaces.

This chapter consists of two major parts. First, a recommended methodology is presented for proper conduct of the design process. Although strict adherence to this methodology may not be possible in all cases, it does provide a useful problem solving framework for this difficult design activity. Secondly, the major problems of system design—i.e., minimizing discomfort and disability glare, achieving ruggedness—are addressed directly with suggested techniques and methods of analysis.

Recommended Design Methodology

The following sections define the major tasks required to complete and refine the design of an effective illumination system.

Information Collection and Assembly

Establishing comprehensive definitions of (1) the characteristics of the application and (2) the specific performance objectives to be met with the illumination system is an important prerequisite for conduct of design activity. One should note that these characteristics and objectives vary significantly, at least at the machine model level and, frequently, on an application-specific level. It is recommended that the designer commence his or her task with a comprehensive effort to collect and assemble data that establish the following information as a basis for subsequent effort.

Machine Data.—Obtain machine design data including mechanical assembly, electrical, and machine dimensional drawings. Verify that the machine construction is as the documentation depicts. Machines are frequently modified in the field, and manufacturers often provide standard assembly drawings that do not include significant user-specified modifications. Small differences in machine construction can radically affect illumination system design.

If practical, establish site-specific electrical operating parameters as a basis for selection of hardware that will perform reliably. These information needs are discussed in detail in chapter 4 of this report.

Assess the potential for illumination hardware integration into machine design. The machine for which the system is being designed should be inspected, preferrably in the presence of someone intimately familiar with both machine operation and construction (manufacturer's representative or appropriate mine maintenance personnel). Existing dead space should be documented as well as practical machine modifications for creating accommodations to recess lighting hardware. Additionally, the feasibility of installing add-on protective structures should be assessed. Care should be taken to insure adequate provision for anchoring these structures and to insure that they will not interfere with machine operation. Comprehensive photographic documentation should accompany this assessment because it will greatly facilitate the subsequent design effort. The photographs should include size reference; e.g., a candidate luminaire.

One should define the machine servicing requirements and procedures. It is important that the lighting system does not significantly impede accessibility for conduct of these tasks.

On machines where the machine deck serves as a base for work activity, especially roof bolters, spatial allocation for tool and supply storage and for work surfaces should be defined. This accommodation should be considered as part of the lighting system design.

Regulations.—Determine the maximum and minimum dimensions of the workplace to be illuminated, keeping in mind future working places where the machine will be applied. Establish whether the illumination system must meet high- or low-seam regulations or both.

Compile pertinent illumination system regulations and Mine Safety and Health Administration (MSHA) policies that apply to the specific machine in question. These data should include the areas required to be illuminated, types of luminaires permitted at various machine locations, and any other special conditions that apply to the machine and seam height. The current lighting regulations and the latest enforcement policies are included in appendix A. Questions regarding the design and application of lighting systems should be directed to the following agencies:

Regulations and Enforcement: MSHA, Box 1166, Building F, MSHA Academy, Beckley, WV 25801.

Hardware and System Approval: MSHA Approval and Certification Center, Box 201B, Industrial Park Boulevard, Triadelphia, WV 26059.

Application Assistance: MSHA Technical Support Center, Box 1166, Building F, MSHA Academy, Beckley, WV 25801.

Assess Visual Needs Through Task Analysis.—Task analysis is an important basis for illumination system design. The general procedure for conducting this analysis involves

a. Defining major tasks (e.g., tramming, positioning the face drill, pulling trailing cable, etc.) performed with or in the vicinity of the machine.

b. Defining the information required for safe and efficient performance of various mining tasks.

c. Defining the specific visual features that provide the required information.

The result of such analysis is a definition of principal work stations, workers' lines of sight, visual attention locations, and relative acuity needs. Use of this basic information will improve decisions regarding appropriate illumination and will identify areas where consideration of glare is most critical. The best resource for this information is direct contact with the machine operators, ideally those same individuals who will be utilizing the illuminated machine, since this will identify task procedures that have been adopted at the particular mine. Some discretion will be necessary in prioritizing these visual needs, since a comprehensive analysis covering all task procedures and visual requirements is impractical. Also, it is important not to neglect changes in work procedures with respect to different parts of the mining cycle (e.g., advance versus retreat mining).

Establish User Preferences for Hardware.—The designer should attempt to comply with general user preferences for particular hardware design features (contact maintenance and electrical supervisors and safety directors). Rationale for these preferences should be requested, and hardware performance criteria considered most important should be identified.

Document Relevant Mine Conditions and Likely Hardware Damage Mechanisms.—Mine conditions have great bearing on the requirements for system ruggedness. In this regard, important criteria include

Ratios of machine dimensions to entry dimensions.

Bottom undulations.

Bottom conditions that may require machines be frequently pushed.

Roof conditions where draw slate falls on a miner-loader could be a problem.

Salt use in mine, which could cause problems with corrosion of exposed aluminum.

Potential rock falls between adjacent supports on longwalls.

Table 7 lists mechanisms that have frequently been responsible for damage of luminaires on the various face machines and it identifies mine conditions that make these mechanisms a particular problem. The information in this table, with an appropriate complement of site-specific data, can provide a useful basis for establishing a hardware deployment scheme that will exhibit adequate ruggedness.

A Suggested Technique for Information Assembly.—A good working document for the subsequent design effort can be constructed by developing a series of transparent overlays. A separate overlay can be constructed to document each information category that has been defined on a spatial basis; e.g., work stations-lines of sight, feasible recessing locations, areas required to be illuminated to the 0.06-fL standard, machine servicing requirements, relevant luminaire damage mechanisms, etc. These provide convenient documentation and one or more can be overlaid on a line drawing of the machine to assist the designer in consideration of the multiple interrelated factors bearing on a successful design solution.

Generate Illumination System Concept Alternatives

As previously explained, because of the numerous and interrelated technical considerations involved, mine lighting system design is very complex. It is currently best accomplished through a trial-and-error approach making extensive use of simulators. The objective of this task is to present a procedure to efficiently establish the "top" alternative concepts for the application in question. These alternatives will undoubtedly present performance tradeoffs. Accordingly, final selection of the best alternative is the subject of the "Illumination System Concept Evaluation Considerations" section. A recommended procedure for establishing these alternatives is as follows.

Selection of Hardware Candidates.—For practical reasons, preliminary selection of candidate hardware for the design application is necessary before detailed system design commences. Major hardware performance differences on the basis of their salient design features have been discussed in chapter 4 and will not be further detailed here. A recommended procedure for identifying good candidates for system design is as follows:

1. Using application characteristics as defined in the "Information Collection and Assembly" section, establish strict specifications on hardware performance (e.g., power parameters, lumen output requirement). Application of these specifications to the candidate hardware will eliminate certain categories from consideration.
2. Compare viable hardware alternatives and evaluate the relative merits of each type. This procedure should identify the particularly weak contenders and permit their elimination from consideration.
3. Explicitly identify the weak points of the remaining hardware alternatives. For each weak point, assess the feasibility of compensating for this weakness in system design for this application (e.g., placing fragile luminaires where they will not be damaged).
4. Summarize (e.g., tabularize) performance characteristics and the relative feasibility of compensating for weakness for each of the remaining alternatives. Select the top

Table 7.—Common mechanisms that mechanically damage luminaires on mobile coal mine face machines

Mechanism	Conditions that influence frequency and extent of damage	Machines most vulnerable	
		Type	Locations where damage most likely to occur
Rockfall directly on fixture	Roof-rib conditions—fall frequency, fall massiveness, kinetic energy at impact (i.e., less massive falls cause damage in high entries.)	Continuous miners.	Top-deck (or atop canopy) mounted luminaires, particularly on inby end of machine.
Rock sliding onto fixture when cutting boom raised.	Tendency for rock accumulation on cutting boom (draw slate). Massiveness of rock	..do	Fixtures mounted on cutter boom or just outby boom hinge (primarily headlight lens damage, but also fluorescent fixtures if rock is massive).
Conveyed rock impacting fixture.	Conveyed material size	Loader	Top-deck mounted fixtures near conveyor.
Roof contact with fixture.[1]	Machine frame-height-to-entry-height ratio—higher ratio, greater likelihood of such damage.	Continuous miners.	Top-deck mounted fixtures.
		Bolters	Top-deck mounted fixtures or vertically mounted fixtures that protrude above machine frame.
	Bottom conditions—damage frequently occurs when traversing undulations, particularly for caterpillar-mounted machines.	Cutters	Top-deck mounted fixtures.
	Protrusions from roof (e.g., header blocks).	Loaders	Do.
Rib contact with fixture.	Seam height—fixtures are usually side mounted in low seam heights because roofing is a more immediate hazard. However, ribbing incidents then increase.	Bolters	All side-mounted luminaries, but especially those remote from the drill station on single-head bolters.
		Loaders	Side-mounted or overhanging fixtures on side opposite operator cab.
	Visibility of fixture—fixtures that operators cannot see are damaged more frequently.	Continuous miner.	Do. Fixtures mounted beside overhead canopy plate (occurs during rib cleanup or when turning crosscuts.)
	Bottom conditions—poor bottom condutions may force operator to resort to extreme maneuvering on occasion.	Cutters Face drills	Side-mounted fixtures on outby end of the machine.
		Shuttle cars.	Fixtures protruding from side of machine.
Bottom contact with fixture.	Bottom conditions—damage usually occurs when traversing undulations.	Bolters	Low or vertically mounted fixtures on inby and outby end of machine.
Contact with other machines (e.g., when pushed).	Not applicable.	..do	Side-mounted fixtures on outby end of the machine.
		Cutters	Do.
Materials and supplies thrown on deck.	..do	Bolters	Top-deck mounted fixtures.
Pinching between machine parts.	..do	Cutters	Headlights on cutter boom.
		Bolters	Luminaires mounted on drill booms near articulation point.

[1] It is common practice to side mount fixtures in low seam heights because roofing is a more immediate hazard. Because of this, roofing incidents are less significant overall than rockfill and ribbing incidents.

few alternatives on the basis of superior anticipated performance or easy compensation for weak performance, giving greatest weight to those performance attributes that are most important in the application in question. Isolation of one hardware candidate is inappropriate at this time since information will improve as one continues with the design process.

Conduct Preliminary Photometric Analysis.—Before actual design work is conducted in the mine simulator, preliminary photometric work should be done "on paper" so that approximate number of luminaires and layouts can be established beforehand and simulator work can be the "fine tuning" effort it should be. This preliminary analysis involves the following:

1. Calculate the minimum total lumens to illuminate the workplace. An initial estimate of the lumens required can be made by multiplying the total area of all surfaces to be illuminated to the 2-fc (lumens per square foot) level. The actual lumens required will be substantially greater, typically three times this value. This calculation can be used to assess the practicality of using low-output luminaires.

2. Evaluate the advantages of various luminaire illumination distribution (isofootcandle) patterns to assess their relative merits. Photometric curves, generally available from the manufacturers, show the lighting patterns in specific planes through the center of the luminaire. These curves can be overlaid on sketched profile drawings of the machine as shown in figure 41. This task should identify luminaires that have advantageous photometric profiles and provide a rough estimate of the total number and general layout of luminaires required. While helpful, the use of these diagrams is limited since it is difficult to depict the complex three-dimensional shapes of photometric profiles and the additive values of overlapping profiles. Also this technique does not show shadowing and diffusing effects and the lighting profile alterations due to recessing of luminaires, addition of glare diffusers, and protective structure around the luminaires.

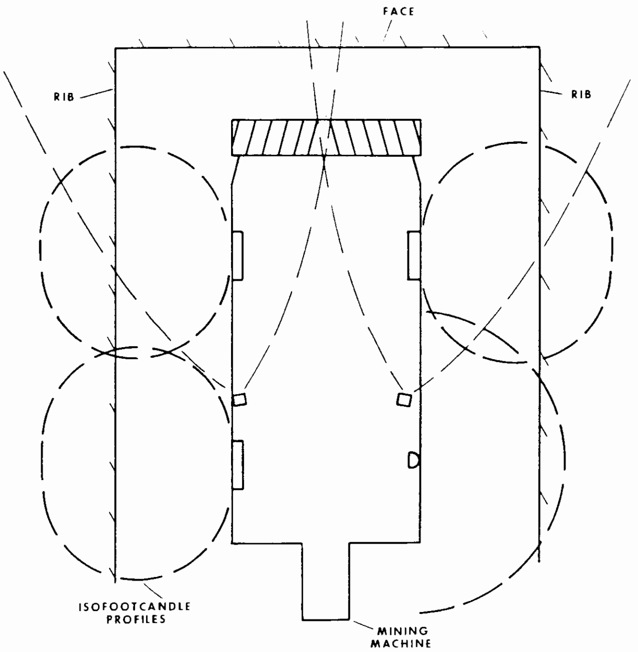


Figure 41.—Example photometric profile diagram.

Resolve Alternative Illumination System Concepts.—A considerable amount of experimental effort is required to develop a good illumination system concept. Most of the work is performed in a mine simulator that duplicates the general reflectivity of coal surfaces. A general procedure for the development and analysis of alternative illumination system concepts follows.

Place the actual machine or a good mockup of it in the simulator at the location specified in MSHA statement of test and evaluation (STE) procedures. A machine mockup should closely simulate the machine profile. Materials that are suitable include wood, cardboard, and styrofoam foam core laminate. The foam core laminate is very easy to work with since it can be readily fabricated into shapes using a simple hand cutter. Complex forms can be constructed by nailing or by gluing shapes together with a hot melt glue gun. The surface of materials should have a maximum reflectance of 30 pct to simulate the minimum reflectance required for machinery surfaces. Remember the MSHA regulations specify that simulator surfaces, including the floor must have a reflectance of less than 5 pct. This can be accomplished with the use of flat black paints or black cloth. The floor must be kept free of loose dirt and dust that can readily increase its reflectance. A typical mine simulator is shown in figure 42.

Select promising design approaches on the basis of the preliminary comparison of specifications and the photometric study. Obtain luminaires for evaluation in the simulator and mount them on the mockup. Measure illumination levels and adjust the system until the required illumination levels are achieved on all surfaces. (Light measurement procedures are discussed in chapter 1.)

Evaluate specific task visibility requirements and adjust the system, as necessary, to provide the task illumination required. For example, this may be the provision of additional illumination of the trailing cable on a loading machine or added control panel illumination on a longwall operator's station.

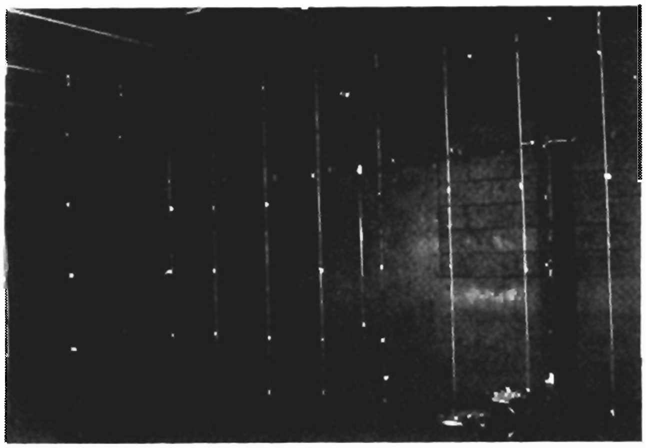


Figure 42.—Typical mine simulator used to establish STE data.

Assess the system from the standpoint of discomfort and disability glare. Install glare shields or develop glare diffusers as needed to improve the system. Consider repositioning luminaires to reduce glare. Examine the system from all of the previously identified principal directions of sight for both the machine operator and associated mine workers. Check to make sure that the design does not impede visual communication between workers in the area when they are at principal work stations. Verify that operators of other machines that may be in the area will not have impaired field of vision. For example, a rear-facing luminaire on a loader may impede the required field of vision of a shuttle car operator if the luminaire is too bright or if its principal direction of light emission aligns with the line of sight of the shuttle car operator.

Resolve component mounting and protection method concepts. Consider recessing components with existing machine structures as much as possible. Add protective guards or bumpers where needed. Consider methods of integrating luminaire mounting within existing structures. Consider methods of mounting illumination components that improve machine access such as hinged luminaires and power supply support structures. Simulate these structures if they may possibly change light profiles.

Resolve more than one viable illumination system concept using other luminaire types and/or arrangements. Compute the relative amount of discomfort glare of each concept from principal worker locations using procedures discussed in IC 9073, chapter 4.

Illumination System Concept Evaluation Considerations

Many factors play an important role in the selection of an illumination system and its components. When more than one system is being considered, the use of a formal tradeoff analysis, such as the comparison in table 8, is recommended to insure an objective approach is used in the selection of illumination system components and the overall design. This approach requires generating alternative illumination system concepts that satisfy the illumination requirements and comparing each of them against the evaluation criteria included in table 8 and discussed briefly in the following sections.

Table 8.—Example illumination system concept evaluation

Design objective	Rating factor	Lighting system concept							
		1		2		3		4	
		Scale[1]	Value[2]	Scale[1]	Value[2]	Scale[1]	Value[2]	Scale[1]	Value[2]
Numeric rating:									
Task lighting effectiveness.	2	3	6	4	8	1	2	1	2
Glare	1.5	3	4.5	4	6	2	3	1	1.5
Area lighting effectiveness.	1	3	3	3	3	3	3	3	3
Durability	.75	3	2.25	2	1.5	3	2.25	3	2.25
Maintenance access	.75	2	1.5	2	1.5	2	1.5	3	2.25
Reliability	.75	2	1.5	2	1.5	3	2.25	3	2.25
Lamp life	.5	2	1	2	1	3	1.5	4	2
Evaluation factor	NAp	NAp	19.75	NAp	22.5	NAp	15.5	NAp	15.25
Subjective rating:									
Number of luminaires	NAp	5		6		6		4	
Component cost	NAp	$3,800		$4,500		$2,000		$4,500	
Installation cost	NAp	$3,000		$5,000		$2,000		$2,000	

NAp Not applicable. [1] Excellent—4, good—3, fair—2, poor—1. [2] Rating scale times rating factor.

Task Lighting Effectiveness

Enhanced illumination of task areas is often desired. Examples of enhanced illumination of task areas are

Increased face illumination for continuous miners, face drills, and cutters.

Enhanced illumination of the room bolting zone and drill chuck on bolters.

Enhanced illumination of machine controls such as operator panels on longwalls, chock actuator valves, methane monitor dials, and machine operating controls.

Glare

The alternative concepts should be compared from the standpoint of discomfort and disability glare especially in the direction of principal lines of sight. Remember that glare is not a function of luminaire brightness alone but also luminaire size, position, background brightness, etc. Concepts with reduced glare should be strong candidates since glare can be a significant cause of annoyance and complaint by workers.

Area Lighting Effectiveness

Area lighting effectiveness is judged by, first of all, determining how well the concept meets the illumination levels required. Secondly, concepts that provide even levels of illumination are preferred since they require less undesirable adaptation as a worker looks in different directions.

Durability

Illumination system durability is a function of both component design and the protection provided by the mounting methods. Therefore, if a highly durable luminaire must be mounted in a manner that exposes it to damage, the concept rating would be low as compared with the rating resulting from mounting a less durable luminaire in a well-protected manner, which could result in a high durability rating.

Maintenance Access

Lighting system components should be evaluated from the standpoint of maintenance accessibility. For example, tasks such as ease of changing lamps or replacing and servicing luminaires in the various mounting locations should be compared for the various concepts. Lamp replacement is a continuing task that should be easy to accomplish to promote system acceptance.

Poorly placed or mounted lighting system components can impede maintenance access to the machine itself. Concepts that minimize machine maintenance access are preferred. Simplicity in troubleshooting the alternative circuit concepts should be evaluated.

Reliability

Illumination system component reliability is a significant factor in coal mine lighting systems. Reliability is difficult to evaluate because of the lack of comprehensive operating and maintenance data on mine lighting components and because component reliability often depends on factors such as the type of machine, mine power system characteristics, and lighting system circuit design characteristics. Because of the complexity of this subject, it is suggested that the reliability of candidate components be qualified through interviews with other users with similar mines, machines, electrical power (ac, dc, and voltage level) and, if possible, voltage variation characteristics. Lighting system component suppliers should be a good source for locating reference mines. Some of the factors that should be considered when assessing the comparative reliability of alternative concepts and circuits have been discussed in chapters 3 and 4.

Lamp Life

Lamp life ratings alone can be very misleading when evaluating the reliability of alternative illumination systems since circuit reliability and operating conditions (including shock and vibration, and voltage variation) can be more important than rated lamp life.

Number of Luminaires Required

A low number of luminaires is a desirable system feature that implies simplicity and generally less maintenance because of fewer lamps. However, the quality of the illumination should not be sacrificed simply to minimize quantity, i.e., the number of luminaires.

Component and Installation Cost

Initial lighting equipment costs, required machine modification costs, and replacement part costs should be compared to identify low-cost viable approaches. Installation costs can vary widely depending on the degree of machine modification required.

A tabular method, such as the one outlined previously, forces the evaluation of each concept with respect to various design objectives and assists in eliminating bias by presenting all of the major assessment factors. For instance, although concept 3 in table 8 is the lowest cost design, its poor task lighting effectiveness may result in the selection of a more expensive approach with improved task illumination. This charting method identifies which concepts have serious deficiencies such as the poor glare rating for concept 4.

Once ratings with respect to the individual attributes of system performance have been defined, the general procedure for applying this method is as follows:

1. Using the information previously developed during the designing of each system, assign a rating to each design objective using the scale indicated, i.e., 1 through 4.
2. Multiply this rating value by the rating factor listed for each objective and record the result on the table.
3. Add the individual scale values to give a numerical evaluation factor for each system. The system with the highest evaluation factor should be the best choice.

In the example shown in table 8, several points related to the use of the table are illustrated.

1. The rating factor value for each objective would be assigned in the order of importance as judged by the user, with the numerical value indicating his or her evaluation of its importance relative to the other objectives. For example, task lighting was considered the most important objective and was 1.33 times more important than glare, twice as important as area lighting, etc. Durability, maintenance access, and reliability were considered of equal importance.
2. No rating factor was assigned to the number of luminaires, component cost, and installation cost objectives because they were considered to have minor relevance to system performance compared with the other objectives. However, if two evaluation factor values are equal or very close, one, or a combination of these three objectives, could be used to make the final system selection. For example, evaluation factors for systems 1 and 2 were close, but system 1 had lower component and installation costs and used one less luminaire. Therefore, since system 1 performance is comparable to system 2, system 1 would appear to be the logical purchase choice.

Install Lighting System

Purchase all components. Prepare detailed drawings of all components, i.e., brackets, guards, etc., that need to be manufactured, and of machine modifications. Emphasis should be on design of highly durable structural components. Install the system in accordance with the STE.

Evaluate Installed System

Illumination system problems and improvements are often revealed when a lighting system is put into service. Followup refinements should be a planned task to insure maximum performance and acceptance of the lighting system.

Conduct a performance evaluation of the illumination system in the mine simulator, if possible, to insure required light levels and uniformity are attained and overheating of electrical components (ballasts, transformers, etc.) does not occur. Assess the performance of the illumination system when the machine is in service underground through interviews with the mine workers including machine operator, helpers, and section supervisors. In particular, monitor normal mining operations to determine whether the lighting component and worker glare protection provided are adequate. Correct problems that exist and submit an STE modification request if necessary. Remember problems such as discomfort and disability glare, poor work area visibility, and poor illumination system performance can substantially affect the mine workers' attitudes, their acceptance of a machine, and indeed worker safety.

DESIGN METHODS AND CONSIDERATIONS

Specific methods to address the major problems of developing an illumination system design are discussed in this section. Emphasis is placed on durability, methods of mounting components, discomfort and disability glare, and luminaire selection.

Durability

All mine luminaires are provided with metal housings or support frames to enhance their durability. Although the luminaires are quite substantial and durable, when improperly mounted or protected they can be very subject to damage. Physical damage of luminaires in the mine environment is a significant problem and a major cause of complaint by mine operators. Reasons for damaged luminaires are

Impact of protruding luminaires against mine surfaces.

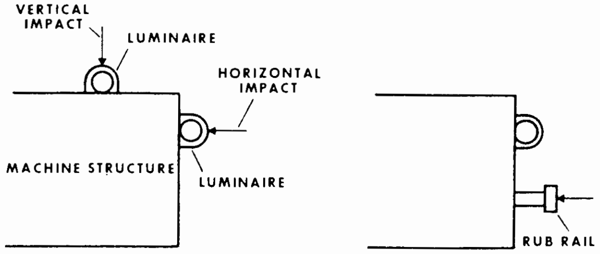
Other equipment impact of luminaires that are not highly protected.

Falling portions of roof. This problem is of course most prevalent on machines operating at or near the face and under unsupported roof.

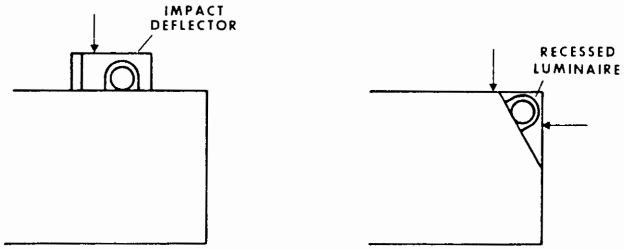
A summary of the common mechanisms that are responsible for mechanical damage to luminaires has been presented in table 7.

Simply relying on the luminaire structure to withstand these impact forces is not a feasible approach when designing an illumination system. If a placement location is subject to these very high forces, other structures are required to protect it. Because of their design configuration, fluorescent luminaire frames are particularly subject to impact damage. The exposed lens surfaces on machine lights are subject to damage if the luminaire is in a vulnerable location. Even sturdy headlamps are easily damaged unless protected.

Some methods of protecting fluorescent luminaires are illustrated in figure 43. Figure 43*A* depicts side and top mounted luminaires, which are highly subject to damage. Figures 43*B* through 43*D* depict installation methods used to substantially improve luminaire durability. If a luminaire must be placed in a location where impacts are likely to occur, it should be protected even at the expense of substantial machine modification if a satisfactory illumination system is to be attained. Recessing luminaires within the machine structure is by far the preferred approach because of the enhanced protection. Effectively recessing luminaires should always be a major objective of the lighting system designer. Examples of damage that can occur to luminaires in the mine environment are shown in figure 44.



(A) POOR PROTECTION (B) IMPROVED PROTECTION



(C) IMPROVED PROTECTION (D) IMPROVED PROTECTION

Figure 43.—Methods of luminaire protection.

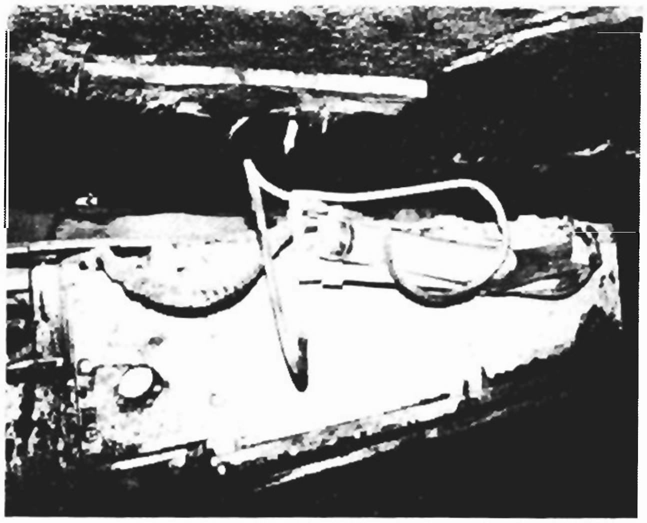


Figure 44.—Example of damage to lighting hardware.

If at all possible, mine operators should work with machine builders so the machine illumination system can be developed as the design of the machine itself is being resolved. All too often the illumination system is thought of as being something that can be retrofitted after a machine has been constructed. Retrofitted illumination systems will most likely result in less than optimum designs and often have significant drawbacks. During the design of a machine, accommodations to recess and protect luminaires in desired locations is much more likely to occur since machine components can be placed and structures more easily designed to provide space for illumination system components. Luminaires mounted using methods to enhance durability and survival in the mine environment are depicted in figure 45.

Component Mounting Methods and Considerations

Mine luminaires, power supply enclosures, and junction boxes are usually supplied with steel pads that can be welded to the machine structure. The component can then be mounted by bolting it to pretapped holes in the weld pads. A typical lighting system consists of one power supply enclosure, several luminaires, one light switch, several junction boxes, and cabling. In all, these components can often occupy a significant area of the machine. If components are poorly mounted, the results can be—

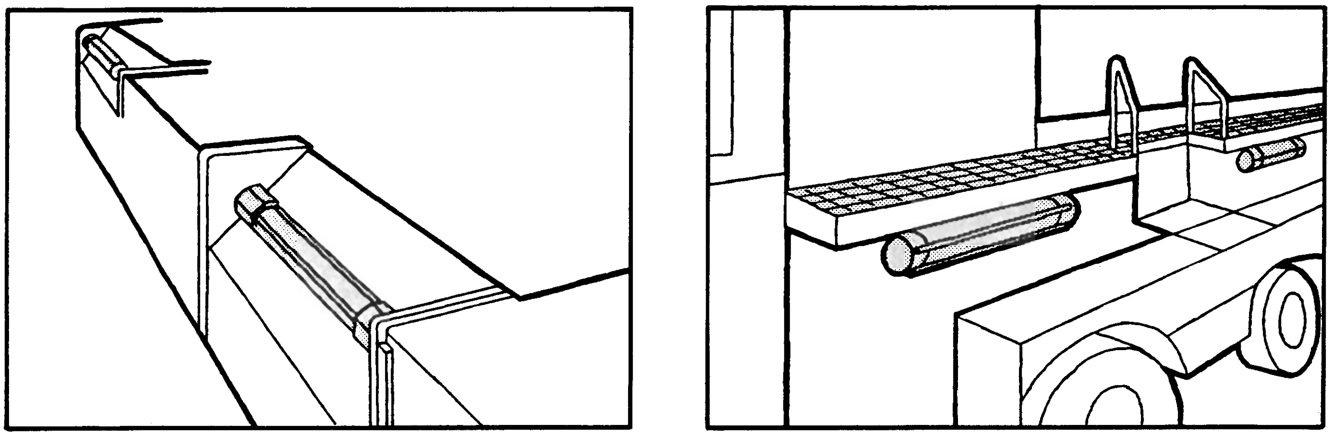
Difficult service access to illumination system components;
Impeded machine maintenance access; and
User dissatisfaction with the lighting system.

Some methods to minimize these problems are presented in this section.

Power Supplies.—If a separate enclosure is used to house the illumination system power supply components, it should be a readily accessible location to facilitate service access. A well-mounted power supply with an integral light switch is shown in figure 46*A*. It is sometimes difficult to place power supplies in readily accessible locations. This is especially the case on compact, low-seam machinery. In figure 46*B* service access to the power supply on this low-seam machine was improved by providing a hinged support for the adjacent luminaire and its support frame. Power supplies can often be mounted on simple hinged structures to improve machine maintenance access. It is much easier to simply rotate the enclosure out of the way compared to removing it from the machine when it impedes access. When hinged structures are provided, cabling can usually be flexed sufficiently and therefore need not be disconnected as in the case where the enclosure must be removed from the machine.

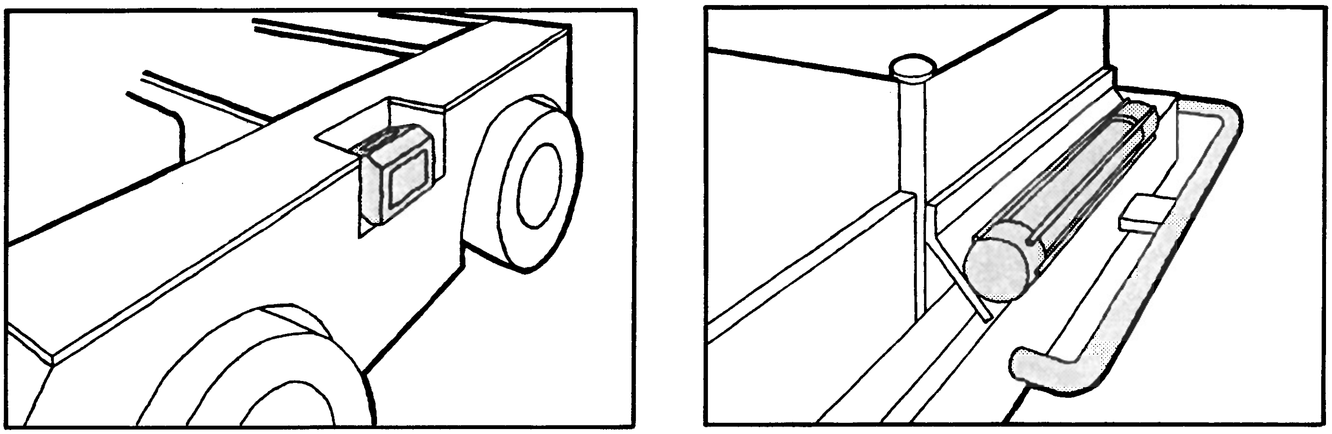
Power supply components can also be placed inside existing machine power and control explosion-proof enclosures if sufficient space is available or was planned in the design of the equipment. The lighting system cost could be reduced using this method since a separate power supply enclosure for lighting would not be required. When using existing enclosures, care must be taken that the added power components do not result in overheating of the equipment in the enclosure.

The Problem of Glare.—The designers of coal mine illumination systems must be very familiar with and sensitive to the problems caused by discomfort and disability



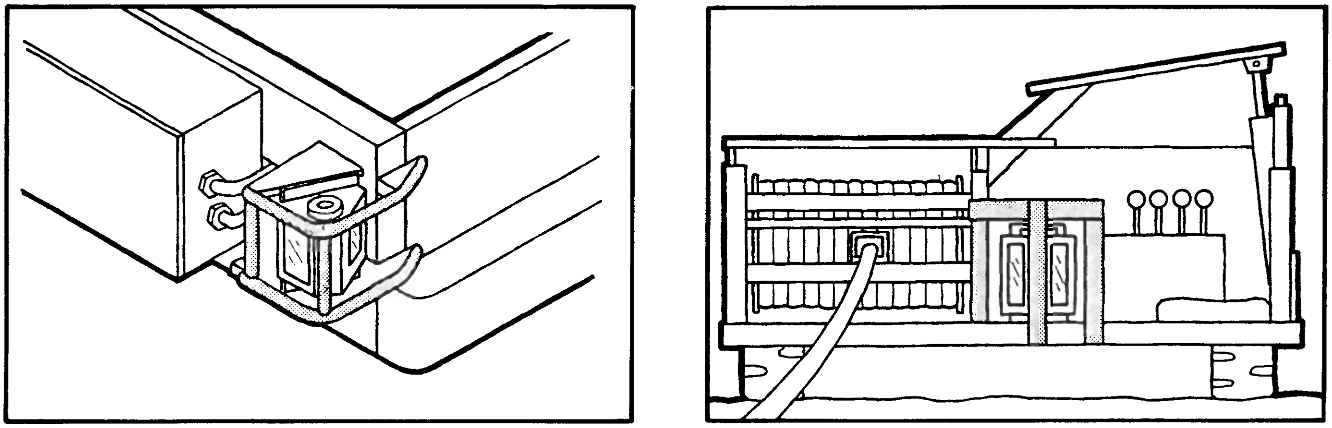
RECESSED LUMINAIRES IN A MODIFIED MACHINE STRUCTURE

ADDED WALKWAY PROVIDES A MEANS FOR LUMINAIRE MOUNTING AND PROTECTION



RECESSED LUMINAIRE IN A MODIFIED MACHINE STRUCTURE

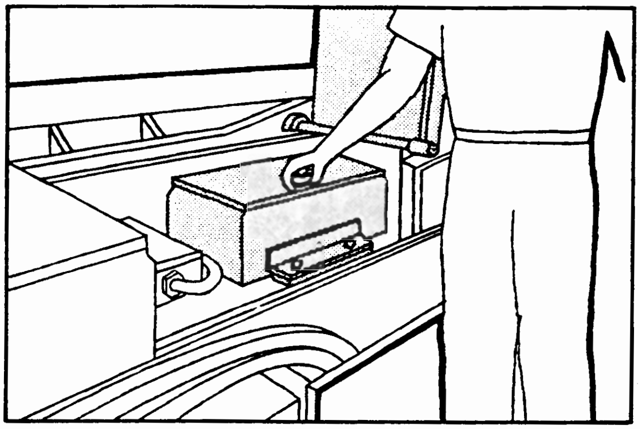
ADDED RUB RAIL TO PROVIDE LUMINAIRE PROTECTION



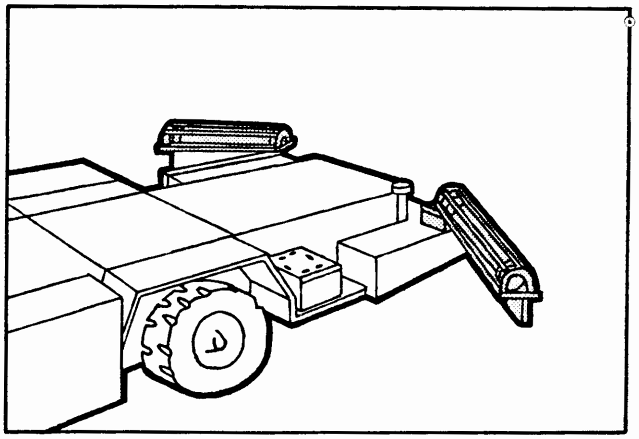
ADDED STRUCTURE IMPROVES LUMINAIRE PROTECTION

ADDED BUMPER PROVIDES LUMINAIRE IMPACT PROTECTION

Figure 45.—Example luminaire mountings that improve durability.



(A) WELL MOUNTED POWER SUPPLY WITH HINGED PROTECTIVE COVER



(B) HINGED LUMINAIRE SUPPORT STRUCTURES FACILITATE MACHINE AND LIGHTING POWER SUPPLY ACCESS

Figure 46.—Example power supply mountings.

glare if they are to develop underground lighting systems that will be well received by the mine workers and which will not impede worker vision or reduce worker visual comfort.

During 1979, two surveys were conducted by a joint UMWA-BCOA committee to identify problems associated with installed underground coal mine illumination systems. The most frequently identified problem that caused dissatisfaction, especially evident in low-seam mines, was glare. The severity of the problem was indicated by the finding that 63 pct of the low-seam miners wanted the lights removed while in high-seam mines 93 pct of the miners did not want the lights removed. However, many glare complaints were received in both high- and low-seam mines. Although in general the high-seam illumination systems were well received by the miners, approximately 85 pct of the illumination systems observed contained problem areas that generated complaints from the equipment operators or helpers. The majority of these complaints were caused by discomfort glare, disability glare, veiling luminance and afterimages from light sources.

The studies identified the following causes of glare:

Light fixtures placed in direct view of the operator or helper.

Light fixture lenses that were not covered with diffusing materials.

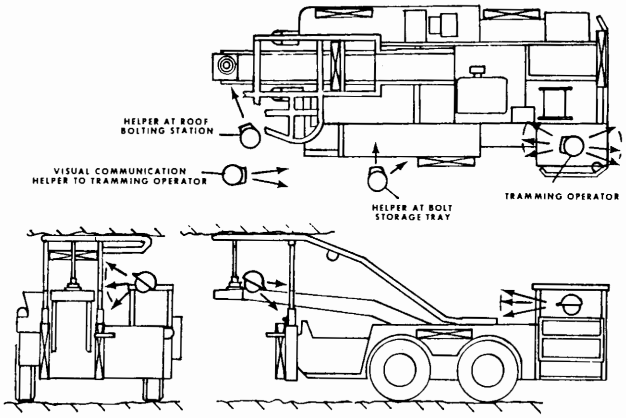


Figure 47.—Example of principal lines of sight for a roof bolting machine.

Improper utilization of glare shielding techniques.

Poorly designed light fixtures.

Lack of space available for adequate installation of lighting.

The studies indicated that in many cases the glare problems could be resolved with lighting system modifications, while some identified problems resulted in recommended changes to the illumination requirements. These survey results illustrate the need for considerable attention to glare when designing, installing, and evaluating illumination systems. The following sections discuss (1) methods to calculate the glare potential of a single luminaire or of a total lighting system, and (2) ways to install luminaires to minimize the glare potential.

Principal Worker Stations and Lines of Sight.—To maximize visibility and minimize glare it is important to determine the principal locations and lines of sight for the machine operator and helpers. By knowing these lines of sight the lighting system designer can—

Stress placement of luminaires in locations where they will not be viewed directly on a frequent basis;

Determine where glare shields are needed;

Identify locations where low-glare luminaires are needed;

Estimate the degree of discomfort and disability glare; and

Consider task illumination needs.

Principal lines of sight are determined by understanding the machine operation and tasks to be performed by the operator and helpers. A typical roof bolting machine is shown in figure 47. As indicated, the bolting station operator has several principal directions of sight including the drill chuck-roof area being drilled, the bolt storage tray, and visual communication with a tramming operator. The tramming operator's principal lines of sight are in the direction of vehicle movement. It is these lines of sight that need particular attention since objectionable glare in these directions will almost certainly result in either visibility impedance or visual discomfort. Higher levels of glare can often be tolerated when the glare source is not located on a principal line of sight and when the source significantly improves task visibility.

Methods To Evaluate and Reduce Disability Glare.—The two most significant forms of glare encountered in underground coal mines are disability glare and discomfort glare. In this section, methods to evaluate and reduce disability glare will be discussed. The reader is referred to IC 9073 (chapter 4) for a more in-depth discussion of the disability glare equations.

Disability glare, which by definition reduces visibility, will also reduce visual performance. For example, when a miner directs his or her cap lamp in your direction the ability to see the miner and his or her surroundings are diminished, just as oncoming car headlamps significantly diminish your ability to see the roadway at night. Any light directed by a source in the field of view towards your eye will detract from your ability to see in the direction of the source. No simple method is available to determine the acceptability of a mine lighting system from the standpoint of disability glare. Methods are, however, available to reduce and to evaluate the disability glare of alternate lighting system designs on a comparative basis. Methods to reduce or eliminate disability glare include the following:

The use of shielding to eliminate a glare source.
Repositioning a luminaire.
Increasing task and background luminance levels.
Changing the orientation of a luminaire.
Selection of luminaires that reduce illumination levels impinging on principal worker stations.
Use of retrofitted glare diffusers.

Let's examine some of these methods as they relate to the disability glare equations presented in IC 9073 (chapter 4). A light source in the field of view of an observer creates a veiling luminance which can be represented by the equation $L_v = 10\pi E/\theta^2$. L_v is the veiling luminance, in footlamberts; E is the illumination, in footcandles, at a plane passing perpendicular to the line of sight of the observer; and θ is the angle between the observer's line of sight and the glare source as depicted in figure 48.

The apparent contrast of the task is represented by the equation $C' = L_d - L_b/L_b + L_v$, where L_b is the background luminance, L_d is the luminance at the object, and C′ is the apparent contrast between the visual task and its background as perceived by the eyes of the miner.

First of all notice that C′ is maximum when L_v is zero. Therefore, presence of any light source visible to the miner reduces the apparent contrast of the visual task. As the value of L_v is increased, a point will be reached where C′ is reduced to the threshold for perception, as indicated in figure 49.

At this point the task object cannot be discerned from its background. It can, therefore, be concluded that visual perception is maximized when no glare sources are present in the visual field, and when glare sources are present, visual performance is enhanced as the level of L_v eminating from a glare source is reduced.

The use of shielding to eliminate a glare source is often a very effective method to reduce or eliminate a disability glare problem. The use of glare shields to maximize the visibility of a continuous miner operator is illustrated in figure 50.

Note that without the glare shields, the miner's ability to perceive the face, ribs, roof, and floor would be substantially diminished.

Repositioning a luminaire can significantly reduce disability glare. Notice in the equation for L_v that its value can be reduced by increasing the angle, θ, or reducing the amount of light, E, from the glare source that impinges on the observer. For example, in figure 51A a luminaire is placed close to a roof bolt storage tray near the principal

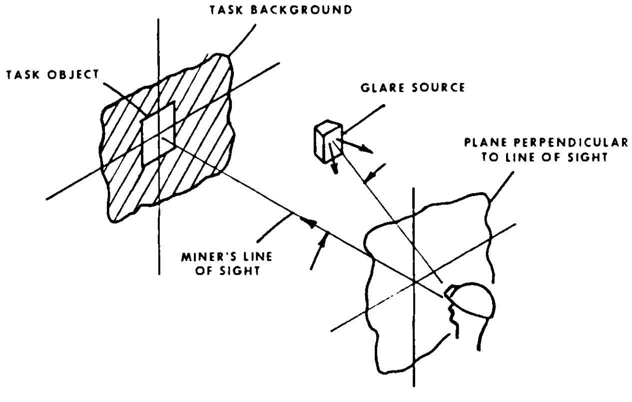


Figure 48.—Disability glare diagram.

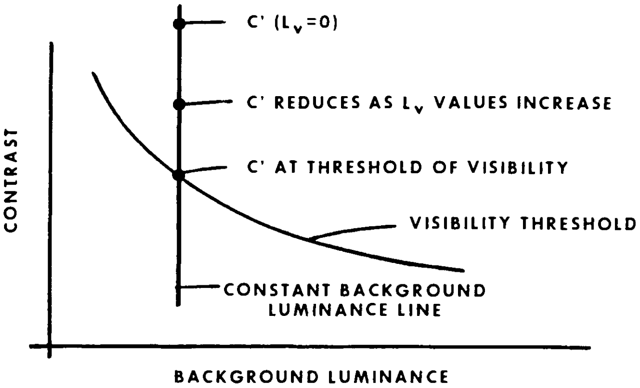


Figure 49.—Apparent contrast versus visibility.

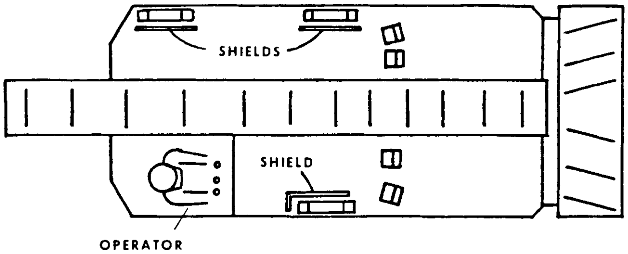
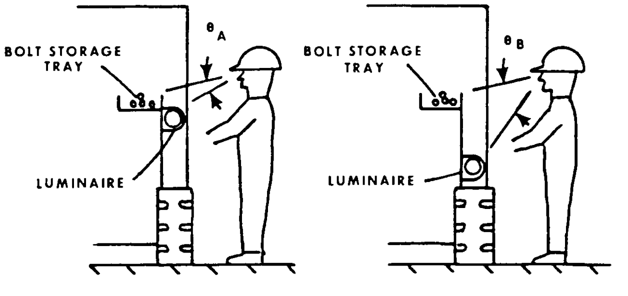


Figure 50.—Glare shields used to reduce disability glare.



(A) HIGH DISABILITY GLARE (B) REDUCED DISABILITY GLARE

Figure 51.—Disability glare versus luminaire position.

line of sight of the mine worker. In figure 51*B* the luminaire is shown repositioned to reduce disability glare. Assume that the improved positioning shown in figure 51*B* results in the following changes in θ and E values: Let $\theta_b = 5\theta_a$; $E_b = 0.25\ E_a$.

The resulting reduction in veiling luminance, L_v, can be computed as follows:

$$L_{v(a)} = \frac{10\pi E_a}{\theta^2_a}, L_{v(b)} = \frac{10\pi E_b}{\theta^2_b},$$

$$L_{v(b)} = \frac{10\pi(0.25)E_a}{(5\theta_a)^2},$$

$$\frac{L_{v(b)}}{L_{v(a)}} = \frac{10\pi(0.25)\ (E_a)}{(5\theta_a)^2} \mathrm{X} \frac{\theta^2_a}{10\pi E_a} = \frac{1}{100}.$$

The luminaire movement resulted in a reduction of veiling luminance by a factor of 100. This example illustrates the large benefits that can be achieved when the placement of luminaires is carefully considered along with principal lines of sight of the mine workers. Note that with the luminaire in the lower position, the mine worker can also avoid looking directly at it while he or she is performing tasks.

Increasing task and overall luminance levels can reduce disability glare if it is accomplished without increasing the luminance of the glare source. For example, assume the face is illuminated to 0.06 fL and the luminance of detail that is being viewed in the face is 0.2 fL. With no glare source in a continuous miner operator's field of view the resultant contrast is $C' = L_d - L_b/L_b + L_v$; 0.2 − 0.06/0.06 + 0 or 2.33.

If there is a luminaire in the miner's field of view that generates a veiling luminance, L_v, of 0.05 fL, the apparent contrast of the detail being viewed will be reduced to $C' = L_d - L_b/L_b + L_v$; 0.2 − 0.06/0.06 + 0.05 or 1.27.

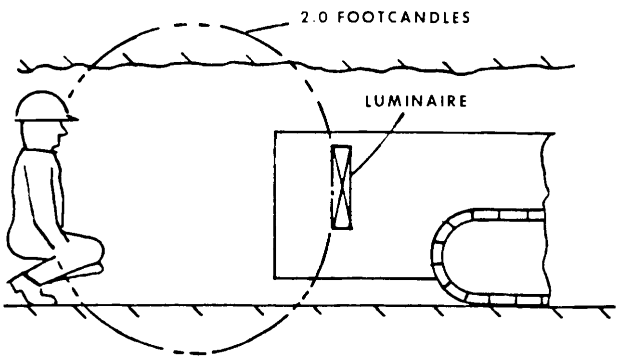
As a result of increasing the face illumination three times by adding additional headlamps, the apparent contrast would be $C' = 0.06 - 0.18/0.18 + 0.05$ or 1.82.

Note that increasing the level of face illumination diminished the impact of the glare source. As a general rule, if the illumination, i.e., light falling on the mine and machine surfaces, can be increased without increasing glare sources in a worker's field of view, it will be beneficial in reducing disability glare.

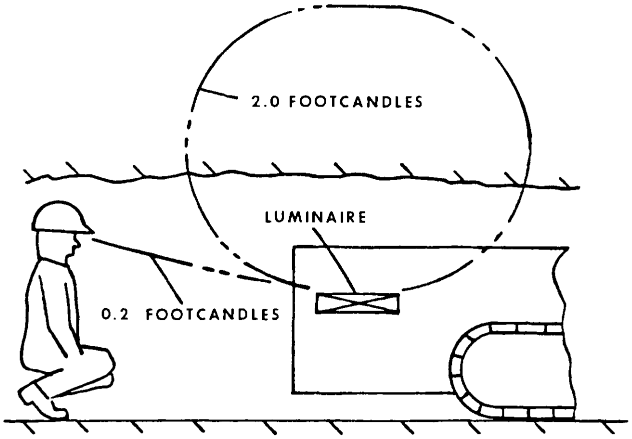
Changing the orientation of a luminaire can at times be an effective method to reduce disability glare. For instance, in figure 52*A* assume the vertically mounted luminaire is a point source that results in a 2.0-fc glare illuminance that impinges on a worker's principal work station. When the luminaire is rotated as shown in figure 52*B* the illuminance is reduced to 0.2 fc as indicated. The resulting reduction in veiling luminance, L_v, can be computed as follows:

$$\frac{L_{v(b)}}{L_{v(a)}} = \frac{10\pi E_b}{\theta^2_b} \mathrm{X} \frac{\theta^2_a}{10\pi E_a} = \frac{E_b}{E_a} = \frac{0.2}{2} = \frac{1}{10}.$$

This reduction by a factor of 10 can significantly improve visibility and decrease disability glare. Often, just small changes in luminaire orientation can reduce glare. This is especially true in low-seam applications where principal worker stations are confined to small areas and where luminaires are very close to the mine worker. This example illustrates the importance of simulating worker stations and evaluating the principal lines of sight when designing an illumination system.



(A) INCREASED DISABILITY GLARE

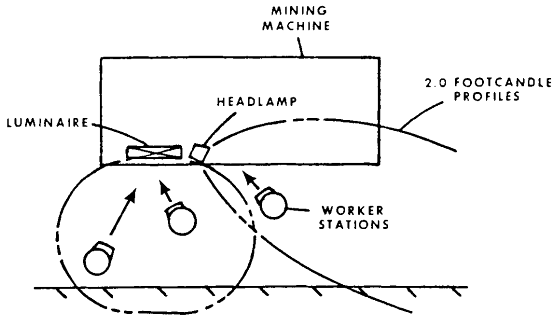


(B) REDUCED DISABILITY GLARE

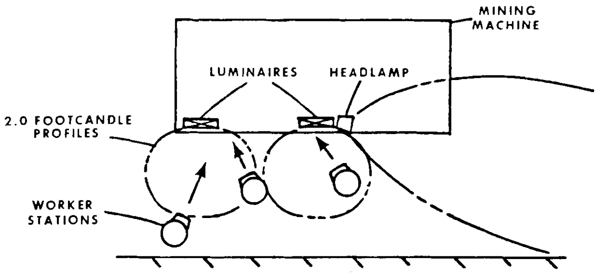
Figure 52.—Luminaire orientation change to reduce disability glare.

Selection of luminaires that reduce illuminance levels impinging on principal worker stations can reduce disability glare. Lumen outputs and light distribution patterns vary widely with sizes and types of luminaires. To minimize veiling luminance levels, the designer should select luminaires that minimize light levels impinging on principal worker stations. For example, the workers in figure 53*A* are exposed to higher disability glare levels than in figure 53*B*. High-output luminaires must be very carefully placed if glare complaints are to be avoided.

Use of retrofitted glare diffusers that reduce the light output of a luminaire in a specific direction can reduce disability glare. These diffusers can be any device that, when placed between the worker and luminaire, reduces the illuminance level impinging on the worker. They can be perforated metal screens, bars, or translucent plastic.



(A) INCREASED DISABILITY GLARE



(B) REDUCED DISABILITY GLARE

Figure 53.—Luminaire selection and placement to reduce disability glare.

Methods To Evaluate and Reduce Discomfort Glare

Discomfort and disability glare are distinctly different phenomenon. When a light source in a miner's field of view causes a sensation of annoyance or, in severe cases a sensation of pain, the light is considered a source of discomfort glare. Discomfort glare is often accompanied with disability glare, which is defined as a measure of visibility or visual performance reduction caused by a glare source. In this section, methods to evaluate and reduce discomfort glare will be discussed. The reader is referred to IC 9073 (chapter 4) for a more in-depth discussion of the discomfort glare equations used.

Discomfort glare often results when a luminaire is located near the principal line of sight of a mine worker. Physiologically, it is believed that the bright source causes the mine workers' eyes to attempt to adjust both to the rather low task luminance and the glare source. This causes a fatigue or annoyance and results in discomfort. The effect of looking directly into the headlamps of an oncoming mining machine is an example of severe discomfort glare.

Both discomfort and disability glare become very significant design considerations when background illumination levels are low, as in underground coal mines. This fact is illustrated by the results of coal mine illumination surveys that indicate that glare is probably the most frequent cause of dissatisfaction with illumination systems, especially in low-seam mines where workers must often be stationed very close to luminaires and often cannot avoid looking towards glare sources. Both the discomfort and disability glare equations as well as common sense support this statement. For example, the glare caused by car headlamps ranges from severe at night to negligible during daylight.

Methods to reduce or eliminate discomfort glare are similar to those to reduce or eliminate disability glare but in some respects differ significantly. They include the following:

The use of shielding to eliminate a glare source.
Repositioning a luminaire.
Increasing task and background illuminance levels.
Changing the orientation of a luminaire.
Selection of luminaires having low surface luminance (brightness).
Use of retrofitted glare diffusers.

Each of these methods will be illustrated in the following discussion.

The state-of-the-art of discomfort glare theory does not allow the coal mine lighting designer to determine whether a coal mine illumination system is acceptable or unacceptable from the standpoint of discomfort glare. It does, however, provide the designer with a means to compare alternative lighting systems and determine in an approximate manner which has less discomfort glare.

The equations for discomfort glare result in the calculation of the following values which are a measure of visual comfort—discomfort glare rating (DGR) and visual comfort probability (VCP).

The DGR value for a single glare source in the field of view of an observer can be computed using the following basic discomfort glare equation: $DGR = LQ/PF^{0.32}$, where L is the brightness, in footlamberts, of the glare source in the direction of the observer; Q is a term that is a function of the size of the glare source and its distance from the observer; P is the position factor, a function of the location of the glare source in the field of view of the observer; and F is a measure of the average field luminance (brightness) including the averaged brightness of the glare source within the field. A complete definition of these terms is presented in IC 9073 (chapter 4). Higher computed DGR values mean increased discomfort glare.

Discomfort glare sensitivity varies widely among individuals. As a result, a specific lighting system may not create discomfort glare for one individual but for another it may be quite discomforting. To accommodate for this variation in population sensitivity, a method for converting DGR values to VCP values was developed. Computation of VCP values (IC 9073, fig. 58) is an effective method to compare alternative lighting systems. General methods to reduce discomfort glare are discussed in the following paragraphs.

The use of shielding can be an extremely effective method to eliminate a discomfort glare problem (see figure 50). Note in the preceding equation that by eliminating a glare source, the value of L is reduced to zero and the DGR value is zero.

Repositioning a luminaire in a manner that increases the position factor, P, can substantially decrease discomfort glare. Note from figure 56 of IC 9073 that position factors vary from 1 to 16 within the field of vision. The position factor is minimum when the glare source is on the observer's line of sight, therefore, glare sources should be offset from a worker's principal line of sight as much as possible. Note from figure 58 of IC 9073 that reducing the DGR value from 800 to 50 (a factor of 16) increases the VCP value from 5 to 95 pct.

Increasing task and background luminance reduces discomfort glare. As discussed in chapter 4 of IC 9073, the field luminance term in the discomfort glare is represented by the equation. $F = L_b \omega_b + L_s \omega_s \theta_s/5$. This means that the field luminance is equal to the average of all the light impinging on the observer within his or her total field of view of 5 sr. Increasing the luminance of the task and background (L_b value) will increase the F term value in the DGR value equation, thereby lowering the DGR value and reducing discomfort glare. Note, however, that increasing the F term by increasing the glare source brightness, L_s, will also increase the L value in the DGR equation, which would increase the DGR value and, therefore, discomfort glare. Because increasing the L_s term will increase the glare source brightness term, L, in the DGR equation more rapidly than the $F^{0.32}$ term, the overall effect is an increase in the DGR value.

Changing the orientation of a luminaire can reduce discomfort glare. Assume the following conditions for the glare source depicted in figure 54*A*.

Distance, R, from the worker to the glare source—5.0 ft.

Projected area of the glare source in the direction of the worker—0.3 ft.^{2}

The source is a good diffuser with a brightness of 500 fL.

Assume the following conditions for the same glare source which has been oriented as shown in figure 54*B*.

Distance, R, from the worker to the glare source—5.0 ft.

Projected area of the glare source in the direction of the worker—0.05 ft^2.

The source is a good diffuser with a brightness of 500 fL.

Assume also that the average background luminance (not including the glare source luminance) is 0.25 fL and the glare source angle, θ, below the line of sight of the worker for cases a and b is 10°.

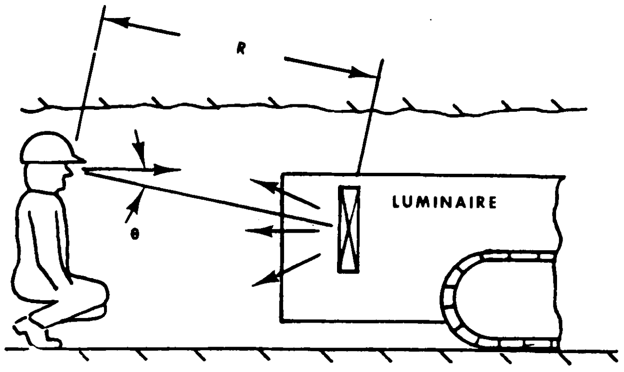
To evaluate the anticipated discomfort glare improvement in case b, the DGR and VCP values can be computed and compared for each case. The source brightness, L, and position factor, P, are the same in each case, therefore $L_a = L_b$, $P_a = P_b$, and $DGR_{(a)}/DGR_{(b)} = (Q_a/F_a{}^{0.32}) \times (F_b{}^{0.32}/Q_b)$.

Using the discomfort glare equations from chapter 4 of IC 9073, $Q = 20.4\omega + 1.52\omega^{0.2} - 0.075$, where ω, the solid angle subtended by the glare source, is equal to $\omega = A_p/R^2$. R is the distance from the glare source to the observer and A_p is the projected area seen by the observer.

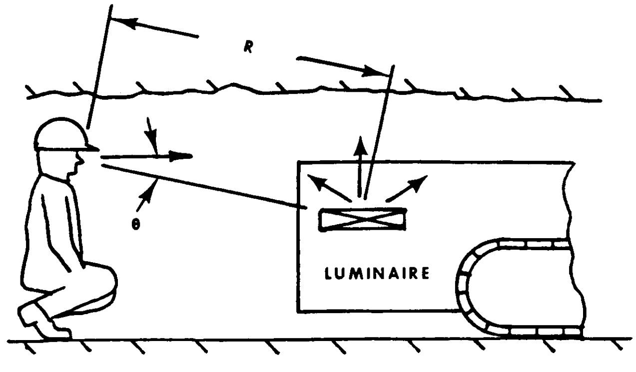
For cases a and b, $\omega_a = 0.3/5^2 = 0.012$ sr; $\omega_b = 0.05/5^2 = 0.002$ sr; $Q_{(a)} = 20.4(0.012) + 1.52(0.012^{0.2}) - 0.075 = 0.8$; $Q_{(b)} = 20.4(0.002) + 1.52(0.002^{0.2}) - 0.075 = 0.4$; $F = {}^{(L\omega)}\text{background} + {}^{(L\omega\cos\theta)}\text{glare source}/5$; ω background = ω visual field − ω glare source; $F_{(a)} = 0.25(5 - 0.012) + 500(0.012)\cos 10°/5 = 1.4$ fL; $F_{(b)} = 0.25(5 - 0.002) + 500(0.002)\cos 10°/5 = 0.45$ fL; and $(DGR)_{(a)}/(DGR)_{(b)} = (0.8/1.4^{0.32}) \times (0.45^{0.32}/0.4)$ or 1.4.

The discomfort glare rating for case a is 1.4 times higher than for case b. By referring to figure 58 of IC 9073, it can be seen that the higher DGR values correspond to lower VCP values. Therefore, the lower DGR value of case b improves the VCP. This example also illustrates the rather complex relationship of lighting system variables as they affect discomfort glare.

Selection of luminaires with low surface luminance (brightness) can reduce discomfort glare. For example, assume the luminaires shown in figure 55 have good diffusing surfaces, differ in luminance by a factor of 2.0, and

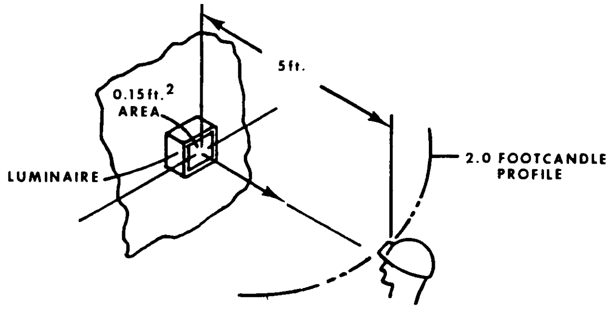


(A) INCREASED DISCOMFORT GLARE

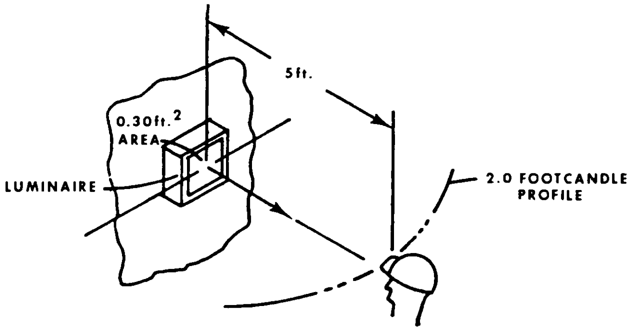


(B) REDUCED DISCOMFORT GLARE

Figure 54.—Luminaire orientation change to reduce discomfort glare.



(A) INCREASED DISCOMFORT GLARE



(B) REDUCED DISCOMFORT GLARE

Figure 55.—Discomfort glare versus luminaire brightness and area.

produce equal illumination levels of 2.0 fc at the observer location. In this example $F_a = F_b$ and $P_a = P_b$.

The glare source brightnesses are calculated using the following relationship: $L_a = \pi ER^2/A_p$; $\pi(2)(5^2)/0.15$ or 1,047 fL; and $L_b = \pi(2)(5^2)/0.30$ or 524 fL. The solid angle subtended by each source is $\omega_a = A_p/R^2$; $0.15/5^2$ or 0.006 sr; and $\omega_b = 0.30/5^2$ or 0.12 sr.

The source size-distance factor for each luminaire is $Q = 20.4\omega + 1.52\omega^{0.2} - 0.075$, $Q_a = 0.59$ and $Q_b = 0.80$, and $DGR_{(a)}/DGR_{(b)} = (L_aQ_a)/(P_aF_a^{0.32} \text{ X } P_bF_b^{0.32})/L_bQ_b) = L_aQ_a/L_bQ_b$; 1047 (0.59)/524(0.80) or 1.5.

The discomfort glare rating for the bright source in case a is 1.5 times greater than case b even though the illuminance provided is equal. Therefore, using luminaires with reduced surface brightnesses can reduce discomfort glare when the luminaire must be within the field of view of a worker and discomfort glare is a problem. Note, however, that in many lighting installations the use of brighter small sources may be preferred because of luminaire placement, and orientation or shielding advantages. Also the directional characteristics of small, very bright sources such as headlamps can at times allow the designer to reduce glare by directing the beam away from worker's principal lines of sight.

The use of retrofitted diffusers can reduce discomfort glare. The mining machine depicted in figure 56 has two rear-mounted fluorescent luminaires, which are required to provide illumination of the floor, ribs, and roof areas near the rear of the machine. It was also desirable to illuminate the floor area behind the machine to provide good visibility of the trailing and control cables. The use of standard fluorescent luminaires in these locations resulted in a significant degree of discomfort glare for the machine operator, whose principal work station is behind the machine.

To reduce this glare, translucent plastic diffusers were placed between the operator and luminaires as shown in figure 56. The diffusers reduced the discomfort glare rating at the operator's principal station by a factor of 2.5 while permitting maximum illumination of the ribs, roof, and floor adjacent to the machine and providing rearward illumination. The use of opaque glare shields would have further reduced the discomfort glare. In this case opaque shields reduced the task visibility of the cables and floor behind the machine to undesirably low levels and use of the translucent diffusers was the best overall system.

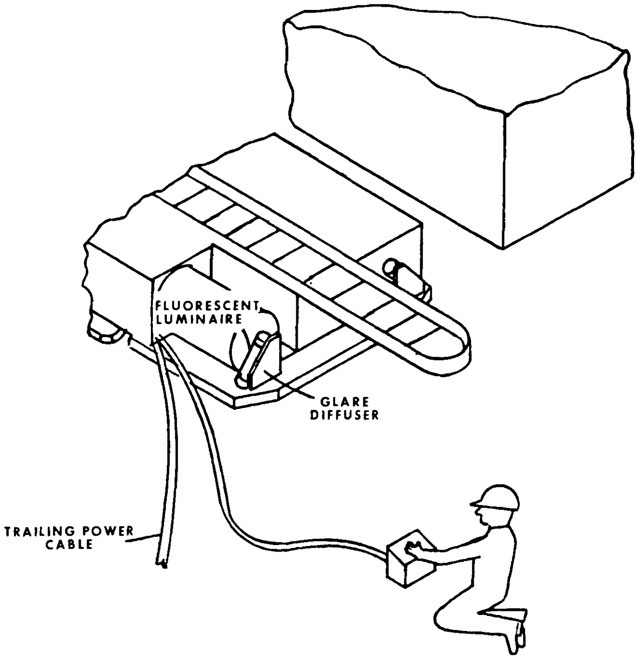


Figure 56.—Example of retrofitted glare diffusers.

The brightness of current mine lighting luminaires cannot be reduced. As a result, at times, retrofitting diffusers is the best alternative available to the designer.

The preceding example as well as the more in-depth discussion in chapter 4 of IC 9073, illustrate methods to analyze and reduce discomfort glare. These analytical methods provide means to understand discomfort glare and to analyze alternative solutions in an objective manner. It is hoped that further research in this area will result in the recommendation of specific DGR and VCP levels for coal mine lighting.

CHAPTER 6.—INSTALLING AND MAINTAINING MINE LIGHTING SYSTEMS

The salient features of lighting hardware (chapter 4) and system design (chapter 5) are not the only factors having impact on lighting system performance. Installation and maintenance techniques also have a very significant bearing. This chapter presents installation and maintenance guidelines aimed at minimizing installation costs, improving component service life, minimizing machine downtime, ensuring acceptable system performance, and assisting in diagnosis of the cause of certain lighting problems. As such, it is directed at shop and maintenance supervisory personnel employed by the face equipment manufacturers, rebuild shops, and mines.

GUIDELINES FOR SYSTEM INSTALLATION

It is essential that installers realize the effect the quality of their work will have on the subsequent performance of the lighting system. They should be aware of the numerous measures they can take (most are relatively minor in nature) to improve the protection of components, facilitate future servicing of lighting components and the machine itself, and improve performance of the system from a lighting viewpoint. Mine operators should insist on high installation standards from in-house and independent rebuild shops and original equipment manufacturers. In the case of the latter two, detailed specification of installation practice should be provided. What follows is an outline of major considerations important to a successful lighting system installation.

Preparation

Typically installers are given an MSHA statement of test and evaluation (STE) package that includes the layout drawings and wiring schematics to be used as the primary documents guiding the installation. These documents alone comprise an incomplete guide to installation, and installers should realize that they should take care in regard to unspecified aspects that have been left to their discretion. A review of STE specifications, in light of the actual machine upon which the system will be installed, should be performed before work is initiated. Important check points include the following:

1. Do STE and actual machine model numbers correspond precisely (not just "root" model numbers)? If not, the STE may not be valid for the given machine.
2. Do machine dimensions given on the layout drawing in the STE and on the actual machine correspond? Again, discrepancies will void the STE approval. Often, machine profile will differ because of optional equipment additions and changes made during previous rebuilds. In such event installers should contact lighting suppliers about obtaining an approval extension to cover their machine.
3. Do suitable anchor points exist for mounting luminaires at the locations specified on the STE layout drawing? Unless greater tolerances are specified on the layout drawing, luminaires must be installed within 6 in of the location specified and at an orientation within 5° of that specified. In some early designs, oversights in the use of machine mockups resulted in such anchor point problems.
4. Although the STE design should have been thoroughly reviewed prior to lighting system installation, a final review should be conducted at this time. Are luminaires located where they are particularly vulnerable to damage, where they will interfere with machine function (e.g., cable winding or boom swing), where they will hinder machine servicing, or where they are likely to cause glare problems? In the event of serious problems, it is suggested that a design modification be pursued.

Mounting Luminaires

Always bolt-connect luminaires to their mounting brackets so they can be readily removed; never weld luminaires to mounting brackets.

Before mounting luminaires, compare their layout with the layout of machine covers. Luminaires that span more than one cover will hinder machine servicing. If possible, refabricate covers, altering their layout to eliminate this situation.

Welding luminaire mounting brackets to explosion-proof enclosures and permissible panels is not recommended because the heat from welding can cause warpage of the enclosures and panels. Bolt connection is, of course, impossible, because it would violate the permissibility of the enclosure. If the STE requires a fixture to be mounted atop an explosion-proof enclosure, attach the luminaire and bracket to a piece of plate that can span the enclosure. Support this plate on pieces of bar and bolt it to the machine at each end, at points adjacent to the enclosure.

Mounting tabs are prone to breakage on many aluminum fixtures such as headlights. Take great care in preparing a mounting surface, making sure that it is flat so that stress is not introduced when bolting down the fixtures. Do not overtorque mounting bolts. Also, if possible, do not mount aluminum fixtures on surfaces prone to excessive vibration.

On certain continuous miners installations, it may be desirable to install vertical strips of plating inby headlights to deflect rock sliding back off the boom. Be sure that the plates are not so high that they cut off the headlight beam.

Use of hinged luminaire mounting brackets is generally not recommended because they are expensive to fabricate and, if the luminaire is exposed, bending quickly renders the brackets useless. In cases where a quick-release mount is desirable, the bracket shown in figure 57 is recommended. It is easier to fabricate than a hinged bracket and much more durable.

The quick-release bracket shows the same advantage as hinge brackets when transporting machines; luminaires are simply released from the top deck and are wired to the side of the machine. Hinge brackets are, however, often beneficial on recessed luminaires (where the brackets are not so subject to damage) because they facilitate access to the luminaire for maintenance and lamp changing.

It is frequent practice to fabricate 45° angle-brackets for fluorescent luminaires from a single length of angle iron and plate. Such brackets block transmission of light to the machine deck, reducing visibility of objects on the deck. It is recommended that angle brackets be sectionalized (e.g., using three supports, one at each end and one at the center) instead of a single length. Alternatively, windows might be cut into the solid bracket to allow light transmission.

When heavy-duty luminaires (e.g., most incandescent and high-pressure sodium (HPS) area luminaires and headlights) are installed, assess the strength of the luminaire mounting surface and determine underlying components. Rockfalls and other harsh impacts can drive these fixtures into the machine body and cause serious damage to underlying components. Reinforcement of the mounting surface may be warranted.

If possible, when bolting down luminaires, utilize rubber washers to act as shock and vibration dampeners for the purpose of increasing lamp life.

Mounting brackets on longwalls should be of quick-release design to facilitate takedown in event of damage, blasting, or panel move.

Housing and Connecting Power Conditioning Equipment

The most efficient arrangement for mounting the lighting system power conditioning equipment is to house it in the machine contactor box. Therefore, prior to ordering auxiliary explosion-proof boxes, an assessment should be made to determine if some, or all, of these components can be mounted in the contactor box, possibly eliminating the need for an auxiliary box, or reducing the necessary size of

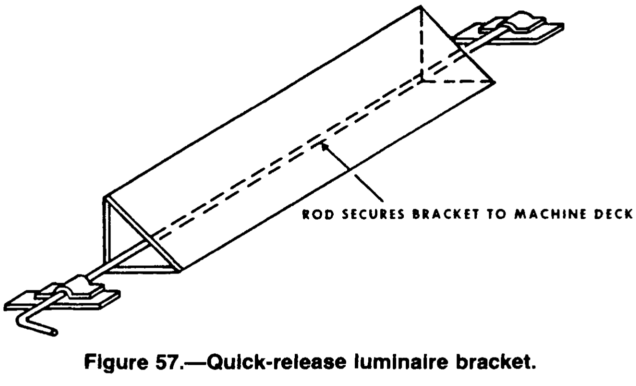


Figure 57.—Quick-release luminaire bracket.

such a box. Sizes of the auxiliary power conditioning boxes available from the hardware supplier should be reviewed carefully. Generally, smaller boxes are preferred because it is easier to find installation sites for them. However, packaging of lighting components within these boxes should be reviewed regarding (1) accessibility of components for electrical tests and component replacements, and (2) heat sinking (stacked ballasts may cause temperature problems).

Important criteria for locating auxiliary power supply boxes include the following:

1. Locations within machine profile are preferable to minimize potential for internal damage from impacts.
2. On remotely ballasted or intrinsically safe systems, attachment to the machine frame should provide good heat dissipation (i.e., ideally attach so that the box has a high contact area with a machine surface of substantial thickness). This is desirable since most of these systems depend on the machine for adequate heat sinking. Also, boxes should not be mounted near heat sources on the machine.
3. Mounting locations subject to excessive vibration should be avoided. Both solid-state and core-and-coil ballasted systems are subject to failure from vibration.
4. Cab-mounting should, in general, be avoided because the boxes will crowd machine operators and the generated heat may be a source of discomfort.
5. Accessibility of the boxes for future servicing is of primary importance. This aspect should not be compromised if the boxes are integrated into machine profile.
6. On longwalls, locations out of the main walkway are preferable as long as the boxes are accessible.

If extra headlights are installed in addition to those required on the STE (a common practice on continuous miners and loaders), check to see that the transformer supplied with the system has adequate kilovolt-ampere capacity to accommodate the additional lamps. When the extra headlamps are low voltage, line losses should be taken into account in this assessment.

Attach accurate wiring diagrams within explosion-proof boxes as an aid to future servicing of the system.

Do not use nominal machine voltage as a basis for connecting power leads to the lighting system transformers if alternative taps are available to accommodate deviations in actual machine voltage. Rather, it is best to base this connection on voltage measurements taken with the machine idle on the particular section the machine will be used.

Cable Installation

Care in routing and protecting cables is extremely important in all applications. Even when cable failure frequencies are not very high, incurred costs can be high because—

1. Shorted cables can be the cause of other electrical failures (e.g., some ballasts overheat and quickly fail when lamp leads are shorted);
2. Troubleshooting delays can be significant depending on circuit design; and
3. Cable changeout times can be significant (up to several hours) because of the difficulty in pulling and reinstalling cables through difficult routing paths and because of the necessity of repacking the explosion-proof glands.

Route luminaire power cables under machine covers wherever possible but (1) avoid "pinch points" where cable can be squeezed between the cover and an underlying component if the cover is impacted, and (2) be sure that covers through which a cable is routed cannot easily shift and pinch or shear the cable.

Inverted angle iron or pipes provide good protection for short top-deck or boom cable runs. Extended top-deck runs protected in this manner may create problems in servicing the machine if adjacent cover pans are spanned or if cables must be reinstalled.

Care should be taken when installing cables that must pass through machine articulation points (e.g., booms, adjustable canopies, temporary roof supports. Cables should be tied back in a manner such that slack is adequate to prevent excessive tension (and eventual fatigue damage) when the joint is articulated and not so loose that the cable is easily snagged.

Leave extra slack under machine covers upon which luminaires are mounted so that covers can be removed and set aside for access to the machine without removing the luminaire from the cover.

If luminaire or explosion-proof housing packing glands are available in different angular orientations (e.g., straight, 45°, and 90°), gland angles should be selected and installed to permit direct routing of cables under machine covers without sharp bends. This will minimize cable exposure and stress damage to conduit, insulation, or conductors.

Although use of luminaires with attached pigtails and connectors is recommended for maintenance reasons, there is a tendency for operators to install these luminaires with the entire pigtail-connector assembly exposed. Care should be taken to route the pigtail directly under a machine cover, if possible. Optimum pigtail length will vary depending upon application of the luminaire, and standardization on a particular length for preassembly purposes may be undesirable. It is recommended that operators examine their particular applications to determine optimum pigtail length or lengths and have their replacement luminaires prewired accordingly.

Junction boxes should be installed to break long cable runs where cable removal and reinstallation is difficult. Numerous mines have reported machine downtimes on the order of several hours for making such replacements. An application of a junction box on the luminaire side of conveyor cross-over channels is particularly useful because of the difficulty of removing and reinstalling cables through these typically crowded and dirt-plugged channels. A field modification may be required to enable installation of these boxes.

On machines where the top-deck is used as a working surface and for carrying tools and supplies (roof bolters in particular), construct compartments and racks on these machines to accommodate these materials. Randomly throwing materials on the top-deck can frequently result in damage to cables and glands, and can also have an undesirable effect on light distribution.

Conductor length between high-pressure sodium (HPS) lamps and ballasts should be limited to a maximum of 20 ft to prevent dissipation of the high voltage starting pulse created by HPS ballastry.

On systems where a number of luminaires are connected across the line to a power distribution lead (especially the low voltage dc systems), it is preferable that junctions be located as close to the source as possible to minimize line losses.

Gland Protection

Although explosion-proof packing gland replacement costs (in terms of parts cost and labor requirements) are generally low compared with costs of other lighting maintenance items, gland maintenance is given high priority at most mines because damaged glands void the permissibility of the lighting system and create a potentially hazardous condition.

How Glands Are Damaged.—Fall of draw slate and roof rock is the most significant cause of gland damage. Minor slate falls will frequently damage glands without significantly damaging luminaires or other explosion-proof enclosures. Other damage mechanisms include (1) impacts incurred when workers throw tools and supplies on the machine deck (a particular problem on roof bolters), (2) contact with roof and ribs (more of a problem on certain fixtures where orientation of gland entrances results in gland exposure to roofing or ribbing), and (3) pulling of the cable from the gland entrance by various means. Design of the gland structure has significant bearing on the incidence of damage from impact and contact forces, and the reader is referred to chapter 4, "Available Mine Lighting Hardware," for a discussion of important design factors to consider in this respect.

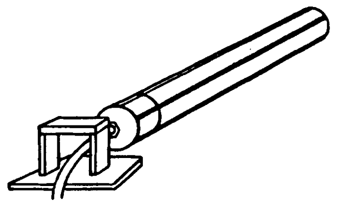
Design of Gland Guards.—Regardless of gland design, auxiliary guards and protective structures can be employed to reduce the incidence of gland damage from impact-contact forces. Care should be taken in the design of these structures; numerous guards employed in the field have proven ineffective because they were underdesigned. It is recommended that the following criteria be observed when designing gland guards:

1. Thick plate or bar should be used to construct the guards. Thin and unreinforced plate, angle iron, or half-pipe sections are inadequate to withstand impacts.
2. Leave substantial space between the guard structure and gland. This permits easy access for gland inspection or removal. Moreover, guards too close to the gland are easily pushed into the gland structure if deformed when impacted. A 2- to 3-in spacing between the guard and gland will permit the guard to bend into the yieldable cable rather than into the gland structure while breaking the impact. Figure 58 shows some recommended guard designs that meet these criteria.
3. The cable feeding luminaires mounted alongside canopy structures on the cabs of various machines are often used as a handhold for exiting the cab, and eventually the cable is pulled from the gland. Installation of a handle on the canopy will prevent this tendency.

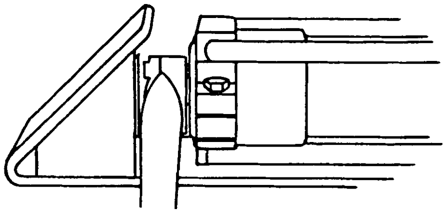
GUIDELINES FOR SYSTEM MAINTENANCE

Lighting system failures can have important consequences to mine operators for the following reasons:

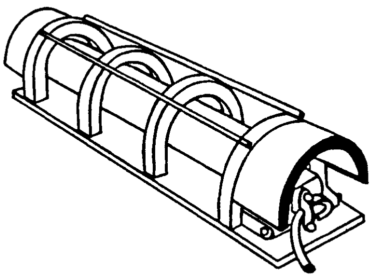
1. Repair costs, in terms of replacement parts and labor, are often significant, frequently several thousand dollars per machine on an annual basis.
2. To legally operate a production machine, lighting systems must be operable. Hence, lost production costs may be incurred because of lighting failures.
3. Electrical failures which void the permissibility of the machine create a serious safety hazard which may result in an accident or citation.



A. "BAR"-STYLE GUARD (APPROPRIATE FOR ANY STYLE LUMINAIRE OR X/P HOUSING)



B. GLANCE GUARD (APPROPRIATE FOR FLUORESCENT LUMINAIRES ONLY)



C. CAGE OVERHANG (APPROPRIATE FOR FLUORESCENT LUMINAIRES ONLY)

Figure 58.—Recommended gland guard designs.

4. Failures may result in noncompliance with the Federal illumination standards and a possible citation.

First, this section addresses approaches to the maintenance of lighting systems. Here, suggestions are given for general procedures to improve (1) the degree to which the system operates "up to spec," and (2) the efficiency of maintenance operations, i.e., minimizing costs. Second, common hardware failures are discussed giving information to assist in establishing the cause and minimizing the frequency of such failures.

Maintenence Approach

Mine operators have long recognized the great potential for improving mine productivity by increasing the availability of the production machines. This has served as an impetus, in recent years, for more sophisticated maintenance programs, which include implementation of improved maintenance scheduling, preventive maintenance, record keeping, parts inventorying, and mechanic training. To minimize the burden posed by lighting maintenance, it must become an integral part of all these programs. Specifically, the key elements of an efficient approach to lighting maintenance include the following:

1. Quick repair of failures at the face through component exchange, with subsequent detailed fault identification and component repair and salvaging performed at more suitable locations.
2. Routine scheduled and preventive maintenance of the lighting system.

3. Maintenance record keeping for use in decision-making.
4. Mechanic training to familiarize these individuals with unique aspects of the lighting system and instruct them in procedures to follow in maintaining it.

Exchange Maintenance

Exchange maintenance is the process of system repair through the exchange of failed system modules (i.e., component groupings) with good modules, without detailed fault analysis of the particular failure(s) within the module. Advantages of this approach to maintaining lighting systems, over the alternative of detailed isolation of the failure and replacement-repair of failed components only, are the following:

1. Troubleshooting time is reduced because fault isolation among the components comprising the module need not be performed at the face. Only the failed module need be identified.
2. Assuming use of hardware compatible with exchange maintenance, overall repair time is reduced because component exchange can be performed quickly.
3. Lighting troubleshooting knowledge requirements for the face mechanics are minimized, enabling them to perform lighting maintenance efficiently.
4. When repairs are made during production shifts, lost production costs are minimized because the machine will be idle for a shorter period of time.
5. Detailed repair work is done at a more favorable environment than the mine working face.

As implied in the preceding, the selection and deployment of hardware compatible with changeout maintenance is necessary for the approach to be successful. Basically, system hardware must exhibit the following two characteristics:

1. Common electrical failures should manifest themselves in such a manner that it is obvious, or ascertainable by minimal electrical testing, which system module has failed.
2. Mechanical assembly of the system is such that the physical exchange of modules can easily be accomplished.

The following are specific hardware design aspects to consider in regard to these characteristics.

Series wiring of lamps (both incandescent and gas discharge) is undesirable because common failures (burnt-out lamps, bad ballasts, short circuit, etc.) may result in the same obvious manifestation—the lamps on the circuit do not light. Resolution of the ambiguity when troubleshooting requires performance of a series of tests, which may take considerable time. Neon bad-lamp indicators can aid troubleshooting of series-wired incandescent, but some failures can still cause ambiguity.

Incandescent systems connected directly across the line show advantage in fault isolation over ballasted systems because ballast failure is not a possibility.

Integrally ballasted luminaires show advantage over remotely ballasted luminaires because it is unnecessary to distinguish between failed lamps and ballasts at the face; the whole assembly can be changed out. Moreover, power supply boxes need not be opened for ballast access.

The use of line-installed connectors on the leads to power supply boxes and luminaires is very advantageous. They enable quick module (i.e., luminaire or power supply) exchange without disturbing internal connections. Replacement modules can be prewired so this work need not be done at the face. Finally, connectors facilitate access to conductors for making short-circuit and continuity tests to isolate cable faults. Slip-fit glands also show advantage when making component exchanges but are not as advantageous as connectors.

Junction boxes should be strategically installed to break cable runs and facilitate replacement.

Luminaires constructed so that the lamp housing can be removed and replaced without removing the wiring (see appendix B) show advantage in cases where line-installed connectors are not employed.

Quick-release luminaire mounting brackets, which do not require bolt removal to remove the luminaire, can reduce time for making exchanges. Design of these brackets has been discussed previously.

In addition to appropriate selection and deployment of hardware, an exchange maintenance program should be complemented with a good program for component reconditioning. Independent vendors and original hardware suppliers do this work, and their services should be considered. Typically, they will completely recondition the failed unit to make it operational, by performing the necessary repairs, including replacement of short-life, high-wear parts such as lenses, diffusers, lamps, etc. Some charge a flat rate, exchanging failed units for previously reconditioned ones. Certain repairs, such as glass lens replacement on some area luminaires, cannot be made at the mine and must be made by the original supplier or an authorized vendor. These services are not inexpensive, however, and for this reason it is recommended that mine operators screen failed components before sending them to the vendor. Components needing minor replacement (e.g., bad lamp) should be repaired in-house, whereas components should be shipped to the vendor if fault identification is difficult and repair will require skills, tools, or facilities not readily available at the mine. This can proceed most efficiently if failed units are shipped to a central location and a trained individual periodically screens the units. An adequately equipped bench should be available to the repair person for making electrical tests or identifying faults through good-part substitutions.

The final requirement for implementing an exchange maintenance program is appropriate stocking of replacement units. Inventory levels should be consistent with usage, and an adequate number of units (in particular luminaires and cable assemblies) should be stored at the face with any possible preassembly, e.g., connecting pigtails and connectors, already performed. It should be noted that inventory requirements are somewhat higher for exchange maintenance. For small, low-overhead mines, this may appear to be a significant disadvantage of this maintenance approach, but should be offset by the benefits of improved availability.

Scheduled and Preventive Maintenance

Scheduled maintenance of lighting systems involves making lighting system checks and performing part of routine machine servicing during scheduled machine downtimes and maintenance shifts. Preventive maintenance is the replacement of components with predictable service lives prior to failure. The benefits of these practices include the following:

Lighting failures will become less of a drain on the availability of the machine by reducing the incidence of failures during operating shifts.

Condition of the system is constantly checked and maintained, preventing deterioration that diminishes the utility of the system and may create hazards and/or lead to permissibility citations.

Table 9 provides a checklist for scheduled lighting system maintenance and inspection. It is recommended that these items be incorporated into the general machine inspection programs in place at the mine.

Table 9.—Scheduled maintenance checklist for mine illumination systems

Task	*Action*
Inspect explosion-proof glands.	Check for proper gap. Check condition of sleeve (twisted or dented). Check set screw placement. Check conduit attachment; placement and tightness of hose clamps. Check for damaged or missing guards.
Clean and inspect luminaire lens.	Clean lens in accordance with manufacturer's recommendation. Check bonding of adhesive on glass lens. Look for crazing cracks, splitting or yellowing on polycarbonate; replace if discovered. Check for excessive polycarbonate scratches.
Check cable routing.	Route away from pinch points (especially on longwalls). Check for direct routing to machine covers with minimum exposure and kinking. Check for exposure of connectors.
Check for dim or flickering lamps.	Replace immediately because they can damage ballasts.

Preventive maintenance efforts in lighting are limited because many hardware failures are caused by unpredictable incidents (e.g. impacts) rather than gradual wearout. Exceptions to this on some lighting applications include lamp failures and polycarbonate deterioration (scratching, clouding) through time. Group relamping; i.e., preventive maintenance of lamps; is discussed in detail in the "Group Relamping" section of this chapter.

Record Keeping

Good record keeping is necessary for obtaining reliable statistics on which to base maintenance program decisions. Uses of these statistics in lighting maintenance include the following:

1. Establishment of optimum component inventory levels.
2. Determining failure trends for use in the scheduling of preventive maintenance.
3. Identification of maintenance troublespots and assessment of factors causing failures.
4. Measurement of the performance of maintenance programs.

Optimum inventorying of lighting components is analogous to inventorying any other maintenance item, and procedures will not be detailed here. Also, as noted previously, the primary use of preventive maintenance is in scheduled lamp replacement.

The simplest way to objectively identify maintenance troublespots is to determine mean service life of the system components; i.e., mean time between failure (MTBF). This can readily be calculated from inventory depletion and machine operating records as follows:

$$\mathrm{MTBF} = \frac{\mathrm{NF}}{\mathrm{NS}} \times \frac{N_a\,MS_a + N_b\,MS_b + \ldots + N_x\,MS_x}{N_a + N_b + \ldots + N_x}$$

where MTBF equals mean time between failure for the component under consideration in machine shifts, NF is the number of failures (per inventory depletion records) during the period under consideration, N_a is the number of components installed on machine type a, and MS_a is the average number of machine shifts operated by each type a machine during the period under consideration. The other subscripts represent the different machines on which the component has been installed (e.g., a—miners, b—bolter, c—longwall). The composite second term represents the average number of machine shifts that the component under consideration was operated during the period considered. For electrical components, MTBF values can be compared to rated component life values as an indication of performance; however, realized mine service life is generally less than rated value.

For more detailed problem identification, individual components can be date-tagged when installed on the machine. In fact, some long-life high-intensity discharge lamps have a built-in tagging system. In addition to installation date, it is recommended that the machine on which the component is installed and perhaps the location of the fixture also be noted. When exchanged, service life can be recorded and the component can be examined for signs of the cause of failure. Knowledge of service life, the environment where the component operated, and component appearance upon failure can give insight to the cause of failures and what to do to resolve the problem. The following examples illustrate the application of this information:

1. High incidence of lamp failure of those lamps at the tail end of a longwall panel relative to the middle or head end might indicate that line losses are causing undervoltage-related failures.
2. High heat-related ballast failure rates on a particular machine relative to other machines on a line or load center may be indicative of a heat sinking problem on the machine rather than an overvoltage problem.
3. High incidence of failed headlamps on a particular fixture may be indicative that the fixture is mounted on a high-vibration surface.

Maintenance Training

Lighting circuitry, particularly ballasted and solid-state systems, differs greatly from other mine circuitry and, potentially, may cause confusion for even experienced mechanics and electricians during electrical fault isolation. Maintenance training programs should address mine lighting, familiarizing these individuals with the function of the system and the procedures to be followed in its maintenance. Training program content will vary depending on the hardware types(s) utilized at the mine, and the variety that exists precludes a specific discussion of content here. The following general comments are made, however, regarding the formulation and content of a maintenance training program:

1. Reference sources for troubleshooting information include (a) manufacturer representatives (some offer courses for mechanics), (b) troubleshooting charts and manuals available from lighting hardware manufacturers, and (c) generalized troubleshooting guides available from various lamp manufacturers. Some of the latter are in a very handy format.
2. Content of troubleshooting procedures presented to the mechanics should be given careful consideration. It is doubtful that they will retain detailed procedures comprehensive of the entire fault tree. Rather, selectivity is recommended, defining in simplest fashion possible those procedures that enable quick and efficient isolation of the most likely faults. (An exchange maintenance program makes this approach more practical.) Diagnosis through component exchange is recommended, using duplicate components already in place if possible (e.g., connecting a luminaire known to be good in place of one not operating to establish whether the fault is within the luminaire or the circuit feeding it).
3. Instruction should be given in the use of available troubleshooting and diagnostic aids (e.g., shorting plugs, cathode-heat tester, etc.) and these should be available on the section.
4. Wiring connection diagrams should be attached to the hardware to permit efficient component exchange and minimize the likelihood of miswiring.

RECOMMENDATIONS FOR MINIMIZING LAMP MORTALITY AND LAMP REPLACEMENT COSTS

In underground mines, applications where "rated" lamp service life is realized are more the exception than the rule. Numerous factors are detrimental to realized service life, and correct diagnosis of those particular factors that reduce lamp life in a given application can be difficult. This section presents recommendations for minimizing costs incurred from high rates of lamp mortality and information for assessing the cause of excessive failures.

Assessing Lamp Costs

The following relationship can be used to establish lamp costs on an hourly basis and to determine the most economical lamp among alternatives:

$$\frac{\text{Lamp cost}}{\text{Hour}} = \frac{\text{Operating (power) cost}}{\text{Hour}} + \frac{\text{Initial lamp cost}}{\text{Mean service life (hours)}} + \frac{\text{Lamp replacement cost}}{\text{Mean service life (hours)}}$$

For most industrial and commercial lighting applications, use of this relationship is straightforward. Operating costs can be readily determined from published lamp and ballast wattage figures and local utility rates. Lamp replacement costs can be established by estimating labor charges, given the design configuration and lamp-changing characteristics of the fixtures. Rated lamp life figures published by the manufacturer provide reasonable estimates of life expected in service.

It should be noted that comparative calculations are performed on a lamp equivalent basis. If it takes 15 lamps of type a to do the same job as 10 lamps of type b, then the lamp cost per hour for lamp type a should be multiplied by a factor of 1.5 (15 divided by 10) for the comparison with type b to be valid.

Use of this relationship to establish the cost of lamps used at the coal face is considerably more complicated and may yield results vastly different from those found in other industrial applications. This occurs because (1) rated lamp service life is an inaccurate estimate of actual service life realized in many coal-face applications of lamps, and (2) lamp replacement costs in some coal-face applications can be particularly high if machine-downtime and lost-production costs must be considered. The major implications these factors have on an economic evaluation of mine lamps are as follows:

1. Life values established through site-specific experience are greatly preferred over rated values for making lamp comparisons. If these data are to be established through trial or experimental lamp installations, great care should be taken to assure that mechanical and electrical application parameters are representative.
2. In most nonmining applications of lamps, operating (i.e., power utilization) cost is the most significant determinant of total lamp costs. Here, use of the more expensive types of available lamps is easily justified by their operating costs being lower (i.e., their efficacy, see chapter 3, is higher) and their rated service life being longer than their cheaper counterparts. In mining applications, reduced service life increases the importance of initial lamp cost and lamp replacement costs relative to total lamp operating costs. Hence, use of expensive, high-efficacy lamps on the basis that they are cheaper overall to operate may not be the case in certain mining applications.
3. Lamp replacement costs are usually the least significant determinant of total lamp costs on most nonmining applications. However, in some coal-face applications, it may be necessary to consider machine downtime and resulting lost-production costs in assessing the cost of making a typical lamp replacement. In cases where lost-production costs tend to be very high, e.g., on an extraction machine, the lamp replacement cost variable may be much more significant than power consumption or initial lamp cost. In such applications, using long-life lamps and taking measures to extend lamp life would be critical to minimizing costs. Conceivably, situations could arise where it would be cost effective to pay 500 pct more for a lamp that receives only a 100-pct increase in life. Accurate assessment of lost production costs, often very difficult to accomplish, is essential for making such a determination.

In summary, determining the most economical lamp for a mine application is complex, but, because incurred lamp costs can be significant, efforts at making such an assessment are worthwhile. Site-specific data on expected lamp life and lamp replacement costs are necessary for an accurate assessment.

Assessing Increased Lamp Mortality in Mine Applications

Numerous factors, many unique to mining applications, can reduce realized lamp service life. The following section discusses the mechanisms causing normal lamp failure, delineates factors likely to shorten service life in mine application, and suggests ways to diagnose these causes of shortened life. It must be realized that rated life is not reached by every lamp in an installation, even under ideal circumstances. Rated life normally means the life expected by the average lamp; 50 pct of the lamps will have failed by the time rated life is reached. In the case of mercury vapor lamps, lumen depreciation is greater than other types, and rated life is specified as the point where only one-third of the lamps have failed. Because of low lumen output relative to power consumption, use beyond this time period is not considered cost effective. For some lamps manufactured exclusively for coal-mine application, manufacturers have devalued rated life figures in anticipation of harsh operating circumstances. Hence, if actual life is approaching rated life of these lamps, one should not infer that significant improvements are not achievable. Operators are urged to determine the mean service life of the lamps they utilize (inventory depletion records make such calculations easy) and, if this life falls significantly short of rated values, operators should take measures to diagnose the cause(s) of high mortality.

Factors Causing Increased Mortality of Lamps in Mine Application

Incandescent Lamps

Rated Life.—750 to 1,000 h, 2,500 to 3,500 h for extended service rated lamps.

Cause of Normal Mortality.—Throughout the life of the lamp there is a gradual evaporation of the tungsten filament. This continues to a point where continuity of the filament is broken, ending the normal life of the lamp.

The following are the likely causes of shortened incandescent lamp life in mine application:

1. Machine Vibrations and Mechanical Shock.—When lamps are operating, their filaments are very hot and become somewhat soft and pliable. In this state, they are very susceptible to breaking when subjected to mechanical shock and machine vibrations. Mechanically induced failures can often be diagnosed by visual inspection. Figure 59 illustrates the general appearance of shock and vibration damaged filaments. Rough service lamps, constructed with special filament mounts to resist shock, have been shown to yield significantly improved lamp life in mine application. Vibration service lamps are designed with extra filament supports and utilize a special tungsten with a crystalline structure that makes it more flexible and vibration resistant. The intended application of this lamp is in environments exhibiting high-frequency, low-amplitude vibrations. Their shock resistance is marginal, hence in most face machine applications, rough service lamps are the preferred lamps to utilize. Vibration service lamps might, however, prove beneficial in some mine applications, e.g., pump rooms. It should also be noted that low-voltage lamps are inherently more resistant to mechanical damage because they employ large-diameter filaments. Use of low-voltage lamps (12 and 32 V) has proven very beneficial on many installations and they are particularly recommended on shuttle car applications.

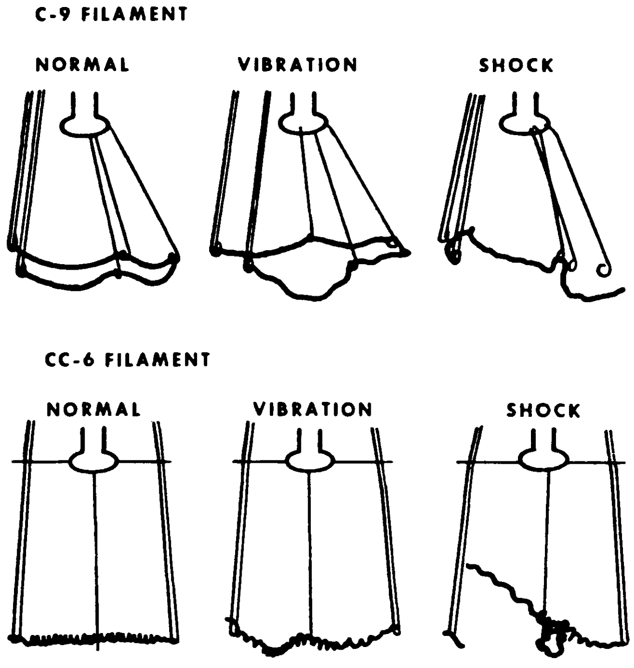


Figure 59.—Effects of vibration and shock on lamp filaments.

2. High Line Voltage.—Incandescent filaments are heated as close to the tungsten melting point as is consistent with reasonable lamp life so that reasonable efficiency in converting electrical energy to visible light energy is obtained. Overvoltage greatly accelerates the tungsten evaporation rate and significantly reduces lamp life. The expected life of an incandescent lamp continuously driven at a particular overvoltage can be computed with the following formula:

$$\text{Expected life} = \text{Rated life}\left[\frac{\text{Nominal voltage}}{\text{Actual voltage}}\right]^{13.1}$$

For example, a 1,000-h, 150-W, 120-V incandescent lamp driven continuously at 130 V would have an expected life of only 350 h, indicating that minor overvoltages (in mining terms) have very serious effects on incandescent lamp life. In general, failures induced by high line voltage cannot be visually diagnosed. Line voltage can be checked with a standard voltmeter; a recording instrument is recommended for an accurate assessment. Note that overvoltages of short duration (e.g., transients) have little effect on incandescent lamp life.

3. Other Instances of Overvoltage.—On dc shuttle cars, installations have been made where the two headlights, wired in parallel, are in series with a single resistor, which drops voltage to the appropriate level for the headlights. When one headlight fails, circuit resistance increases, voltage drop across the resistor decreases, and the remaining operable lamp is overdriven. On a 300-V dc shuttle car

utilizing a pair of 120-V headlights, the remaining operable lamp would see a 43 pct overvoltage, reducing its life to a matter of hours in many cases unless the failed lamp is immediately replaced. Other circuits can be utilized that eliminate this problem and are discussed in chapter 4.

Rapid Start Fluorescent: Standard, High Output, and Very- or Super-High Output

Rated Life.—7,500 to 10,000 h.

Cause of Normal Mortality.—Lamp cathodes are coated with electron emissive material that supplies electrons to initiate and maintain lamp arc. This material is gradually depleted during lamp starting and burn cycles. Normal end of life occurs when emissive material is depleted on one or both cathodes.

The following are the likely causes of shortened rapid start fluorescent lamp life in mine applications:

1. Machine Vibrations and Mechanical Shock.—Vibration and mechanical shock can result in a continuity break in the heater circuit formed by the lamp cathode. Relative to incandescent lamps, resistance to vibration and shock induced failure is high because filament temperatures are lower. If a lamp fails without blackening of the sidewalls, it is likely that failure resulted from mechanical causes (blackening occurs with most electrical failures). On rapid start (RS) lamps, continuity can be checked using a continuity tester across the adjacent lamp contacts on the lamp end. A shadowgraph (fig. 60), permits visual inspection of cathode continuity. The percussive wave of face shooting practiced on longwalls frequently results in mechanical failure of fluorescent lamps. It is advised that longwall systems be equipped with quick-release mounts and line-installed connectors to enable removal of luminaires in the blast vicinity.
2. Low Line Voltage.—Degradation of electron emissive material is greatest during lamp startup. Low voltage prolongs the lamp starting cycle, increasing the rate of depletion of the emissive material and reducing lamp life. Also, on high-output (HO) and very-high-output (VHO) lamps, it is essential that cathode heater voltage be maintained during lamp operation to avoid excessive degradation of the emissive material. Low line voltage will reduce cathode heater voltage during operation and reduce lamp life. Line voltage can be checked with a standard voltmeter (recording instrument preferred) and should be no more than 10 pct less than nominal voltage unless lower levels are specified by the ballast manufacturer. Slow starting is another sign of low line voltages. Low voltage problems may be encountered in cases where line losses are high, for instance at the end of longwall circuits and in mines where voltage regulation is poor.
3. High Line Voltage.—High line voltage tends to cause the lamp to "instant start" without any thermal release of electrons from the cathode. This causes rapid deterioration of the cathode emissive material and reduces lamp life. Line voltage can be checked with a standard voltmeter (recording instrument preferred) and should be no more than 10 pct greater than nominal voltage unless higher levels are specified by the ballast manufacturer. A dense black spot about 1/2-in wide and extending halfway around the tube in the cathode vicinity can be a sign of an overvoltage problem, although similar spots can accumulate for other reasons.
4. Improper Cathode Heating.—As implied, proper cathode heating must be maintained during starting for all RS lamps and for all but standard during operation or the electrode emissive coating will be prematurely exhausted and lamp life shortened. Causes of improper cathode heating include low line voltage, poor contacts at the lamp holder or terminal strips-lugs, ballast problems, or reduced heater circuit voltage at lamp filaments caused by line losses if ballast is very remote from fixture. Improper cathode heating is manifested by dense blackening from the base 2 to 3 in along the lamp similar to normal end-of-life blackening. Blackening caused by improper cathode heating may occur on one or both ends of the lamp. Manufacturers supply heater-circuit testers that are essentially resistors, which serve as a dummy load to draw proper cathode current, and a voltmeter attached in parallel. Go, no-go heater circuit indicators that essentially consist of incandescent lamps to serve as dummy loads, are not recommended for use in troubleshooting mine lighting circuits since low, not zero, heater voltage may be the problem in the case where remote ballasts are used.
5. Wrong Lamp-Ballast Combination.—HO lamps should not be operated on ballasts designed for VHO and super-high-output (SHO) lamps and vice versa. In either case, both ballast and lamp life will be shortened. The effect would be more significant in the case where HO lamps are applied on VHO-SHO ballasts.
6. Improper Ballast Operation.—Improper ballast operation may cause improper cathode heating, low or high starting voltage, and improper operating currents, all of which can reduce lamp life. Check proper operation by making current and voltage measurements specified by the ballast supplier.

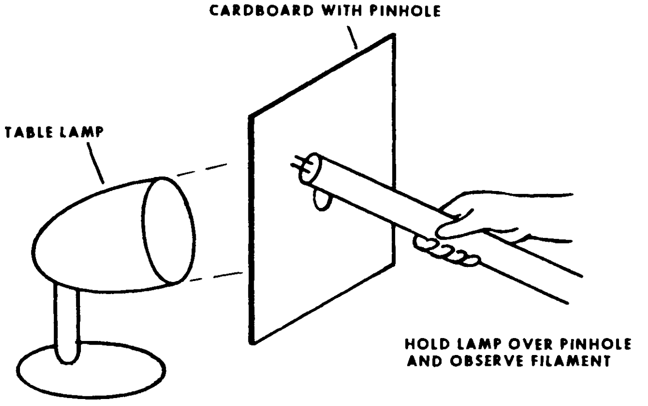


Figure 60.—Shadowgraph to test fluorescent lamp filament continuity.

High Intensity Discharge: Mercury Vapor and High-Pressure Sodium

Rated Life.—12,000 to 24,000 h (mercury vapor, MV) and 7,500 to 24,000 h (high-pressure sodium, HPS).

Cause of Normal Mortality.— In MV lamps, electron emissive material embedded in lamp electrodes is gradually depleted throughout the life of the lamp because of a sputtering off process caused by the impact of arc particles. This occurs to a point where it becomes difficult to produce ionization and strike the arc or to warm up the lamp to full light output. When ballast open circuit voltage is insufficient to strike the arc or warm up the lamp, end of life has occurred.

In HPS lamps, operating voltages exhibit an increase with age (operating voltages in MV and other high intensity discharge (HID) lamps tend to remain constant). This occurs because (1) evaporated electrode materials blacken the arc tube and raise its temperature, which raises the partial pressure of the sodium-mercury amalgam arc material and increases operating voltage (HPS lamps have excess arc material whereas other HID lamps do not); and (2) sodium reacts with the arc tube, increasing the ratio of mercury in the arc material, which also tends to raise lamp voltage. The net effect is an approximate 2-V increase in lamp voltage per 1,000 burning hours. Whenever required lamp operating voltage exceeds voltage available from the ballast, effective lamp life is ended. Unlike MV lamps, HPS lamps will ignite and warmup at the normal end of lamp life; they extinguish as stable operating voltage is approached. Failed lamps will continue the start-warmup-extinguish-cool cycle until power is turned off.

The following are likely causes for shortened HID lamp life in mine application:

1. Machine Vibrations, Mechanical Shock, and Mishandling.—In both MV and HPS lamps, mechanically induced failures are most likely to occur upon (1) break in continuity of the internal leads to electrodes, (2) breaking or cracking of the arc tube, or (3) loss of vacuum between arc tube and lamp outer jacket. Such failures can generally be diagnosed by visual inspection; loss of vacuum will be manifested by oxidation of the metal support structure within the lamp. Lamp electrodes themselves are inherently resistant to mechanical failure. Care should be taken on transport of these expensive lamps into the mine. A loss of vacuum failure can occur if the lamp is too firmly tightened into a socket. Mechanically severe operating environments found on certain machines can cause other mechanical failures other than the three identified.

2. High Line Voltage.—As explained, mortality of HPS lamps is dependent on the operating voltage rise of the lamps. High line voltage raises lamp operating voltage and thus shortens the period that voltage available from the ballast is sufficient to drive the lamp. Excessive line voltage may accelerate the rate of voltage rise of the lamp. The effects of high line voltage are very dependent on ballast design. Regulated or constant-wattage type ballasts or lead-circuit ballasts regulate the effects of line voltage variation and nominally will tolerate a 10 pct overvoltage. Lag-circuit ballasts are poor regulators and will only tolerate 5 pct overvoltage. (See chapter 3 for a discussion of these ballast categories.) Line voltage can be checked with a standard voltmeter. High ballast failure rate in conjunction with high lamp failure rate is a sign that there is a high-voltage problem.

In MV lamps high line voltage will result in excessive temperatures on lamp electrodes and arc tube (MV arc tube material is not as heat resistant as HPS arc tube material) which is detrimental to realized service life. Bulging or shattering of the arc tube is a sign of overvoltage operation. As with HPS lamps, the effects of high line voltage on MV lamps are very dependent on ballast design. Autoregulator and, in particular, regulator ballasts regulate the effects of line voltage variation and will tolerate 10 pct or more overvoltage. Reactor and lag ballasts are poor regulators and will tolerate at most a 5 pct overvoltage. (See chapter 3 for a discussion of these ballast categories.) Line voltage can be checked with a standard voltmeter.

3. Low Line Voltage.—Low line voltage will result in reduced temperature of MV lamp electrodes which, in turn, makes it more difficult for the arc to start during each half-cycle and accelerates the deterioration of electron emissive material. As previously noted, this will eventually raise lamp starting voltage above that which can be supplied by the ballast and hence reduce lamp life. Undervoltage operation should be indicated by an early blackening of the arc tube. The effects of low line voltage are also very dependent on ballast design. Autoregulator and regulator ballasts regulate the effects of line voltage variation and will tolerate 10 pct undervoltage. Reactor and lag ballasts are poor regulators and will tolerate a 5-pct undervoltage. Low line voltage can be checked with a standard voltmeter, with measurement preferably made at normal operating load.

4. Current-Voltage Surges.—Energy from surges can damage the arc tube, arc-tube seals, or leads to arc tube in the outer bulb of MV and HPS lamps. Damage is usually visually evident (damaged seals are evidenced by blackening). This is a likely cause if lamp life is very short.

5. Improper Ballast Operation.—Shorted ballasts (capacitors) cause excessive current and will damage arc tube seals (evidenced by blackening in the seal area) of MV and HPS lamps. Ballast operation can be checked by making current, voltage, and continuity tests according to ballast manufacturer's specifications. Often ballast damage is visually evident—capacitors will be swollen or the unit may be charred.

MEASURES TO IMPROVE LAMP LIFE—LAMP SERVICING SUGGESTIONS

Numerous measures can be taken by the mine operator to improve lamp life once the cause of lamp failure is diagnosed, as is shown in the following examples.

In the case of mechanically induced failures (machine vibrations, mechanical shock, mishandling—

1. Boxes used by lamp manufacturers to package lamps are generally insufficient to withstand mine supply handling methods. Build a cushioned lamp box (e.g., lined with high-density foam rubber) for each mining section and use it to transport replacement lamps;
2. On incandescent systems, utilize low-voltage, rough-service rated lamps. They have thicker, better supported filaments enabling them to better withstand shock;
3. Insure that luminaire mounting surfaces are secure and do not amplify luminaire shock and vibration exposure;
4. Incorporate shock dampening into luminaire mounts; e.g., rubber pads;
5. Review luminaire design to see that it incorporates adequate measures for lamp-isolation and shock-dampening;
6. Use of vibration service lamps may be warranted in some incandescent lamp applications such as pump rooms;
7. On longwalls where frequent face-shooting is practiced, utilize luminaires with line-installed connectors and employ quick-release luminaire mounting techniques so that luminaires in the immediate shot vicinity can be readily removed. Percussion will damage lamps; and
8. On machines where workers pound on machine decks (e.g., changing bits on bolters), take measures such as providing a work surface away from luminaire, move luminaire, etc.

In the case of overvoltage-related failures—

1. On dc machines, size drop resistors in accordance with actual machine voltage, not nominal. Underdriving might be feasible on shuttle cars with twin incandescent headlights on each end because there usually is excess lumen output available;
2. Transformers are available for lighting power supplies with taps for low and high line voltage;
3. Use proper ballasts. Some standard ballasts provided by mine lighting suppliers only tolerate ±5 pct voltage variation. Other alternatives are available (although more expensive and less energy efficient) to tolerate ±10 pct or more; and
4. On dc shuttle cars, there are alternative ways of dropping voltage and driving lamps as depicted in figure 40. The series or series-parallel arrangement is recommended for maximized lamp life, since the remaining lamp is not overdriven if one lamp fails.

In the case of undervoltage-related failures—

1. Transformers are available for lighting power supplies with taps for high and low line voltage;
2. Use proper ballasts. Some standard ballasts provided by mine lighting suppliers only tolerate ±5 pct variation in line voltage. Other alternatives are available (although more expensive and less energy efficient) to tolerate +10 pct or more;
3. Measures that may be taken on longwalls to reduce undervoltage problems include use of autotransformer voltage boosters, larger diameter and/or shorter length conductors, and fewer luminaires per power supply or distribution box; and
4. Correct cable size and length problems if causing inadequate cathode heating voltage on remotely ballasted fluorescent lamps.

It is important to replace failed or dimly burning fluorescent and HID lamps as soon as possible. Failure to do so can result in ballast overheating, damage to other lamps in the circuit, and, in the case of HPS sources, continued recycling of the lamp starter, which will cause its eventual failure.

It is recommended that series-wired incandescent systems be equipped with neon bad-lamp indicators. These devices are simply miniature neon lamps that are shunted across the circuit at each incandescent lamp. When the lamp fails, and causes all lamps to remain dark, the neon indicator at the failed lamp lights, making it simple to identify the bad lamp in the circuit.

GROUP RELAMPING

Group relamping is the scheduled replacement of all the lamps in an installation at the same time, prior to anticipated burnout. This practice, widely utilized in industrial, commercial, office, and sports lighting, has advantages over the alternative—spot relamping (i.e., one-by-one replacement as lamp burnout occurs)—in certain mine lighting applications. Longwall and nonface installations most readily lend themselves to this practice, but it may offer important advantages for some face-machine installations as well. The major benefits of group relamping in a mining application follow:

1. Depending upon the circumstances of the installation, there is potential for considerable savings in maintenance labor requirements for making lamp replacements. Lamp replacement costs in a group relamping program would typically be a fraction of the per-lamp costs for spot relamping because replacements can be made in an organized, assembly-line fashion and piece-by-piece transport of replacement stock is eliminated.
2. By replacing lamps prior to the end of their life, the effects of depreciating light output, which occurs in all lamps as they age, are reduced. The installation is operated at high efficiency, maximizing lumen output per unit of energy consumption. Moreover, lens cleaning (and perhaps lens replacement) would be an integral part of a group relamping program, further improving lighting efficiency. Both these aspects improve the utility of the lighting system and reduce potential for citations.
3. As noted previously, during the lingering-on period near the end of lamp life and, in some cases, after lamp failure occurs, energized ballasts will realize a temperature rise that shortens their useful life. Group relamping prior to failure would significantly reduce such damage.
4. Federal law requires that lamp replacement on all systems that utilize explosion-proof luminaires be made by certified electricians. Group relamping performed on scheduled maintenance shifts would reduce the incidence of spot replacements on production shifts and not detract the work of these key personnel from the production effort.
5. Group relamping is complementary to the exchange maintenance approach advocated in this report; in fact, it makes the changeout approach more viable. On-site group relamping will reduce the incidents where luminaires are removed from the mine just for lamp replacement. This would reduce luminaire inventory requirements for an exchange maintenance program.
6. In cases where lamp failure results in high incurred cost because of machine downtime and lost production, group relamping during scheduled maintenance periods may reduce the incidence of failures during production periods, hence, reducing such costs.

The concept of group relamping hinges on the predictability of lamp life. Figure 61 shows lamp mortality curves (percentage of lamps failed versus percentage of lamp life operated) for the type of lamps utilized in coal mines. The idea is to schedule group replacement prior to the steep part of the curve when failure rates begin to accelerate. The shape of the lamp mortality curve, labor costs for making spot versus group replacement, and lamp costs have bearing on the viability of group relamping and in scheduling the optimum replacement time. A step-by-step procedure for making such an analysis is presented at the end of this section.

In many mining applications, the curves presented in figure 61 may not be applicable since realized life is often less than rated life and also, in such event, the trend of failures need not follow that indicated in the figure. Even though rated life is not realized, this does not mean group relamping is not viable. In these cases, it is necessary to establish installation specific lamp mortality curves by keeping records on lamp replacements (e.g., date tagging

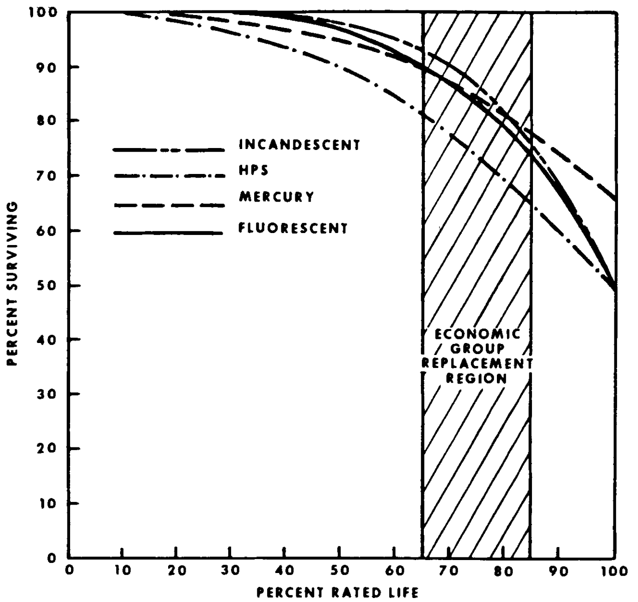


Figure 61.—Laboratory measured mortality curves for lamp types used in coal mining applications.

lamps). If the factors reducing lamp life are random in nature, as might be the case if most failures are the result of mechanical incidents, the shape of the curve might be such as to preclude group relamping; i.e., the rate of failures (the slope of the mortality curve) does not increase as mean service life is approached. In many applications, in particular most longwall and nonface installations, this is not likely to be the case.

On room-and-pillar face machines, random failures are more likely; however, the high machine-downtime and lost-production costs incurred when lamp failure occurs on those machines warrants establishing lamp mortality curves and determining if group replacement is feasible. For example, it may prove very cost effective to replace the headlights on the continuous mining machines every weekend to avoid some of the incidents of downtime for making lamp replacements.

The steps for arriving at the optimum time for scheduling group lamp replacement given a lamp mortality curve (i.e., percent lamp failures versus operating time) is as follows:

1. Determine costs for making one-at-a-time replacements of all lamps in the installation as they fail.

$$\text{Labor cost} = \frac{\text{Labor time (h)}}{\text{Lamp change}} \text{ X } \begin{matrix}\text{Hourly rate}\\ \text{(including overhead)}\end{matrix} \text{ X } \begin{matrix}\text{Lamps}\\ \text{in installation.}\end{matrix}$$

$$\text{Lamp cost} = \frac{\text{Cost}}{\text{Lamp}} \text{ X } \begin{matrix}\text{Lamps}\\ \text{in installation.}\end{matrix}$$

Total cost = Labor cost + Lamp cost.

2. Determine cost incurred as group replacement is made.

$$\text{Labor cost} = \frac{\text{Labor time (h)}}{\text{Lamp change}} \text{ X } \begin{matrix}\text{Hourly rate}\\ \text{(including overhead)}\end{matrix} \text{ X } \begin{matrix}\text{Lamps}\\ \text{in installation.}\end{matrix}$$

(Labor time would be less than that for one-at-a-time replacement.)

$$\text{Lamp cost} = \frac{\text{Cost}}{\text{Lamp}} \text{ X } \begin{matrix}\text{Lamps}\\ \text{in installation.}\end{matrix}$$

Total cost incurred as group replacement is made = Labor cost + Lamp cost.

3. Select a candidate time for scheduling group relamping. Optimally, this time should just precede the steep part of the lamp mortality curve. The candidate time usually should fall in the range of 65 to 85 pct of rated life.

4. Using candidate time of step 3, determine the percentage of lamps that will have failed prior to the scheduled group relamping date. For example, using figure 61, 10 pct of the fluorescent lamps will have already failed if the scheduled group relamping time is 70 pct of rated lamp life.

5. Multiply the percentage of lamps failed, obtained in step 4, by the total one-at-a-time replacement cost, step 1, to determine the cost of making those one-at-a-time replacements necessary prior to the scheduled group replacement. Add this figure to the total cost determined in step 2 to obtain the total cost to the point where group replacement is made.

6. Adjust the cost obtained in step 5 to account for 100 pct expected lamp life as follows:

$$\text{Equivalent cost at 100 pct life} = \text{Step 5 cost X } \frac{\text{100 pct expected life}}{\begin{matrix}\text{Percent expected life}\\ \text{when group replacement}\\ \text{made (per step 3)}\end{matrix}}.$$

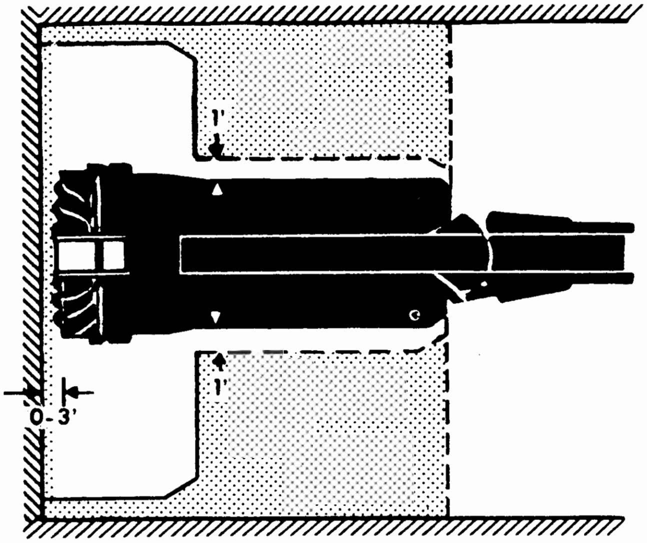
7. Repeat steps 3 through 6 for other candidate group replacement times. Select lowest cost alternative.

From this procedure it is evident that group relamping is most viable when (1) lamps are inexpensive, increasing the significance of the labor savings yielded by group replacement in determining total cost, and (2) the rate of failures accelerates significantly as end of life approaches. It is quite possible that spot replacement as lamps fail may be more economic for expensive lamps that tend to fail uniformly over expected life.

It is essential to note that this procedure does not account for machine-downtime and lost-production costs. If applicable, these costs should be added in step 1 of the procedure. They will have significant bearing on the conclusions of such an analysis, greatly increasing the viability of group relamping and, depending on the shape of the mortality curve, make replacements early in lamp life more attractive.

APPENDIX A.—FEDERAL SPECIFICATIONS FOR LIGHTING FACE EQUIPMENT AND COAL MINE LONGWALLS

A-1.—Continuous mining machine (except rope-propelled auger miners) and loading machines in seam heights greater than or equal to 42 in.



AREAS TO BE ILLUMINATED TO 0.06 fL

The entire coal face and the ribs, roof, floor, and exposed machine surfaces between the face and the point where the shuttle car or other conveying equipment abuts against the mining machine or loader when positioned to receive material.

Note 1.—To allow for most efficient deployment of machine headlights, no light measurements are taken in the **floor** area between the cutter-boom or gathering-head hinge pin and the face.

Note 2.—To permit location of fixtures in maintainable locations, no light measurements are taken within a 1-ft perimeter of the machine.

MACHINE POSITION FOR LIGHT MEASUREMENTS

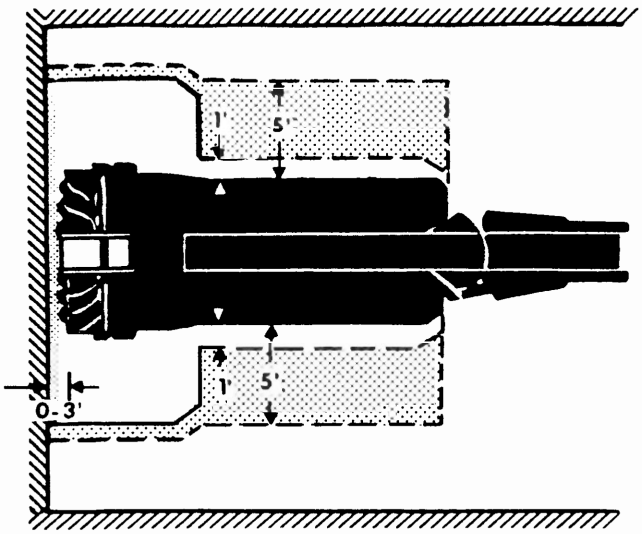
Centered in entry with inby end of cutterhead or gathering head no greater than 3 ft from the face.

ADDITIONAL COMMENTS

Pickup loader, i.e., loaders operated behind a continuous mining machine in surge material handling capacity, fall in this cateory. To prevent objectionable discomfort glare problems, the inby end of these machines are usually not lighting with directional luminaires (e.g., headlights).

Roof lighting not required if seam height is less than 12 in greater than machine frame height.

A-2.—Continuous mining machines (except rope-propelled auger miners) and loading machines in seam heights less than 42 in.



AREAS TO BE ILLUMINATED TO 0.06 fL

Same as A-1 including notes 1 and 2 **except** that light measurements are taken only within a 5-ft perimeter of the machine. Roof, floor, and ribs outside this perimeter need not be illuminated to the 0.06-fL standard. This accommodation is to prevent the necessity of employing undiffused or unshielded high-intensity fixtures to illuminate wide entries often found in low-coal mines. Otherwise, objectionable discomfort glare problems might result.

MACHINE POSITION FOR LIGHT MEASUREMENTS

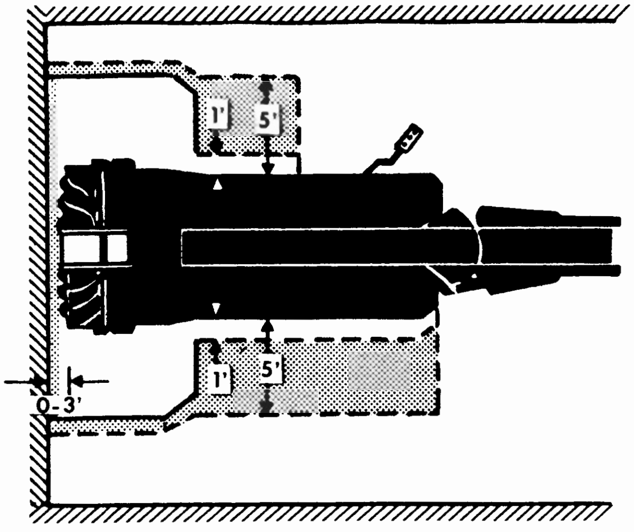
Centered in entry with inby end of cutterhead or gathering head no greater than 3 ft from face. In cases where ribs do do not fall within 5 ft of machine, the machine is repositioned so that it is 5 ft from and parallel to the ribs to take these measurements.

ADDITIONAL COMMENTS

Pickup loaders, i.e., loaders operated behind a continuous mining machine in surge material handling capacity, fall in this category. To prevent objectionable discomfort glare problems, the inby end of these machines are usually not lighting with directional luminaires (e.g., headlights).

Roof lighting not required if seam height is less than 12 in greater than machine frame height.

A-3.—Remote control continuous mining machines in seam heights less than 42 in.



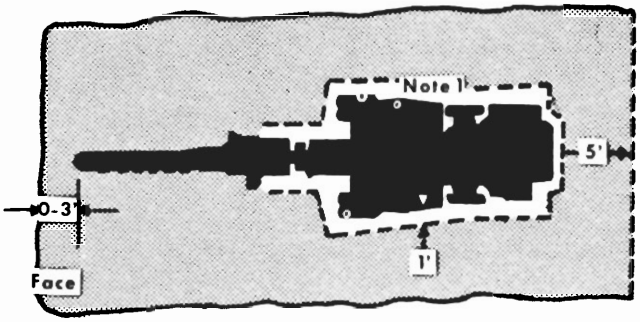
AREAS TO BE ILLUMINATED TO 0.06 fL

Same as A-2 **except** that light measurements are not taken on operator's side of the machine outby the center of the mainframe. This accommodation is to prevent objectionable discomfort glare for the remote control operator. Lack of a stationary operator's station prevents location of a fixture in this area that would not cause discomfort glare.

MACHINE POSITION FOR LIGHT MEASUREMENT

Centered in entry with inby end of cutterhead or gathering head no greater than 3 ft from face. In cases where ribs do not fall within 5 ft of machine, the machine is repositioned so that it is 5 ft from and parallel to the ribs to take these measurements.

A-4.—Face drills and cutters (excluding rope-propelled cutters) in seam heights greater than or equal to 42 in.



AREAS TO BE ILLUMINATED TO 0.06 fL

The entire coal face and the ribs, roof, floor, and exposed machine surfaces between the face and a plane 5 ft outby the machine.

Note 1.—To permit location of fixtures in maintainable locations, no light measurements are taken within a 1-ft perimeter of the machine.

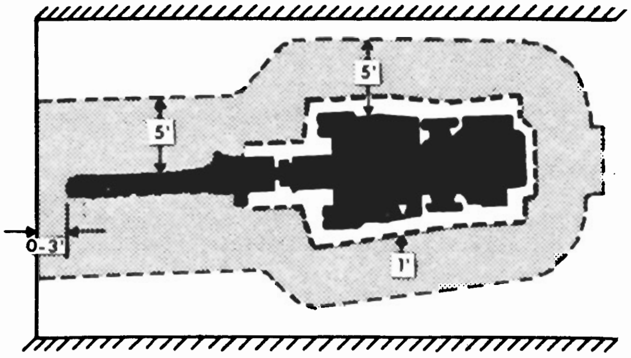
MACHINE POSITION FOR LIGHT MEASUREMENT

Centered in entry with inby end of cutter bar or drill no greater than 3 ft from the face.

ADDITIONAL COMMENTS

Roof lighting not required if seam height is less than 12 in greater than machine frame height.

A-5.—All face drills and all cutters (excluding rope-propelled cutters) in seam heights less than 42 in.



AREAS TO BE ILLUMINATED TO 0.06 fL

Same as A-4 including note 1 **except** that light measurements are taken only within a 5-ft perimeter of the machine. Roof, floor, and ribs outside this perimeter need not be illuminated to the 0.06-fL standard. This accommodation is to prevent the necessity of employing undiffused or unshielded fixtures to illuminate wide entries often found in low-coal mines. Otherwise, objectionable discomfort glare problems might result.

MACHINE POSITION FOR LIGHT MEASUREMENTS

Centered in entry with inby end of cutter bar or drill no greater than 3 ft from the face. In cases where ribs do not fall within 5 ft of the machine, the machine is repositioned so that it is 5 ft from and parallel to the ribs to take these measurements.

ADDITIONAL COMMENTS

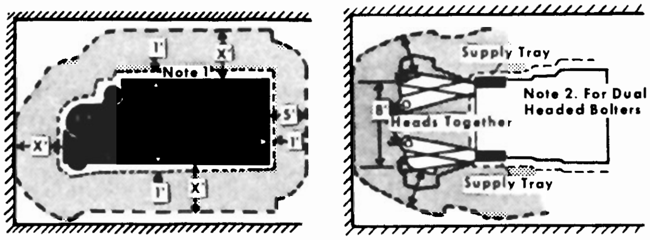
Roof lighting not required if seam height is less than 12 in greater than machine frame height.

A-6.—Rope-propelled cutters and rope-propelled auger miners in any seam height.

AREAS TO BE ILLUMINATED TO 0.06 fL

Pending development of low-glare illumination systems, no illumination is required on rope-propelled cutters. Design and operating procedures for these machines require that jacksetters work inby the machine where they would be exposed to objectionable discomfort glare and cap lamp signaling between these and other workers would be impaired.

A-7.—Roof bolters in seam heights greater than or equal to 42 in.



AREAS TO BE ILLUMINATED TO 0.06 fL

The roof and floor within 5 ft of the outby end of the machine, and the face, ribs, and exposed machine surfaces within X feet of the machine perimeter on all other sides where—

X = 5 ft when seam height is between 42 and 60 in; and
X = seam height, when seam height is greater than 60 in.

Note 1.—To permit location of fixtures in maintainable locations, no light measurements are taken within a 1-ft perimeter of the machine.

Note 2.—Luminaire-adjacent supply trays on dual-head bolters often cause objectionable discomfort glare for the machine operator. To permit location of these fixtures in locations where they will not cause glare, the system is viewed as being in compliance if the required luminance levels are met when the heads are together or when they are spread a distance of 8 ft and in position for installing roof bolts or drilling holes (heads raised). Boom-mounted luminaires can illuminate the supply tray vicinity with the boom spread and eliminate the necessity of locating a fixture here.

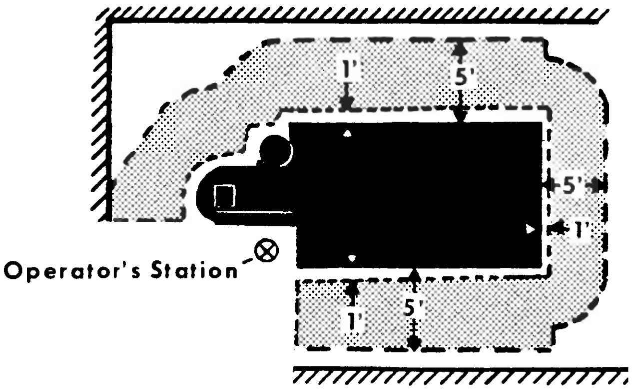
MACHINE POSITION FOR LIGHT MEASUREMENTS

Centered in entry with drill head distance X from the face. In this position, light measurements are taken on roof, floor, ribs, face, and exposed machine surfaces. In cases where ribs do not fall within distance X of machine, machine is repositioned to the distance X from the rib and light measurements are made (two repositionings required). As under note 2, measurements may be made on the supply tray vicinity with the drill heads together or spread a distance of 8 ft and in position for drilling or bolting on dual-head machines.

ADDITIONAL COMMENTS

Roof lighting not required if seam height is less than 12 in greater than machine frame height.

A-8.—Roof bolters in seam heights less than 42 in excluding roof bolters integral to continuous mining machines.



AREAS TO BE ILLUMINATED TO 0.06 fL

As in A-7 (X = 5 ft on all sides of the machine) including note 1 **except** that no measurements are taken in front of the machine at the side of the operator's station. Luminaires mounted in this area cause objectionable discomfort glare in low seam heights where operators would have to work in close proximity of the fixture.

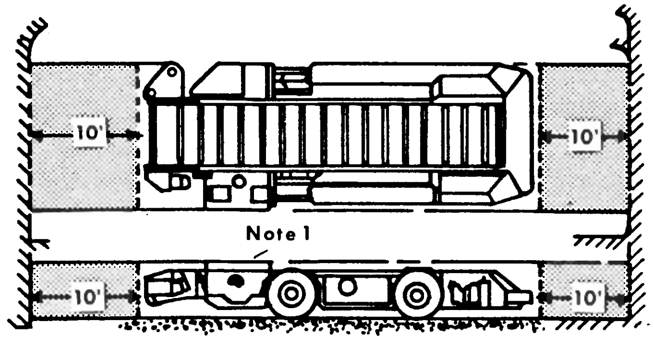
MACHINE POSITION FOR LIGHT MEASUREMENTS

Centered in entry with drill head distance X from the face. In this position, light measurements are taken on roof, floor, ribs, face, and exposed machine surfaces. In cases where ribs do not fall within distance X of machine, machine is repositioned to the distance X from the rib and light measurements are made (two repositionings required). As under note 2, measurements may be made on the supply tray vicinity with the drill heads together or spread a distance of 8 ft and in position for drilling or bolting on dual-head machines.

ADDITIONAL COMMENTS

On roof bolters integral to continuous mining machines, lighting to the 0.06-fL standard is still required in the vicinity of the operator's station. Roof lighting not required if seam height is less than 12 in greater than machine frame height.

A-9.—All shuttle cars, scoops, and load-haul-dump vehicles where specification can be met with fixtures in locations where they are maintainable.



AREAS TO BE ILLUMINATED TO 0.06 fL

The face or rib of coal within 10 ft of both the front and rear of the vehicle within the area defined by the height and width of the machine.

Note 1.—Height is determined by maximum height of machine including sideboards and canopies.

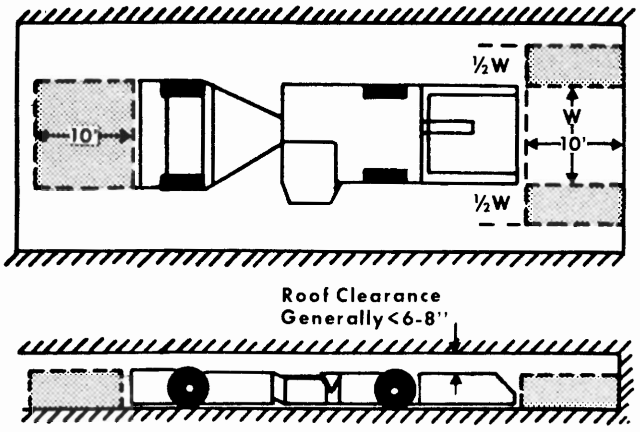
MACHINE POSITION FOR LIGHT MEASUREMENTS

Perpendicular to and between 9 and 10 ft from a relatively smooth coal surface.

ADDITIONAL COMMENTS

Lights only need be operated in the direction of travel at any given time. Lights may be turned off when they become a glare problem for personnel working on continuous mining machine or loader.

A-10.—Scoops and certain load-haul-dump vehicles where specifications of A-9 cannot be met with fixtures mounted at locations where they are maintainable (see "Additional Comments" section).



AREAS TO BE ILLUMINATED TO 0.06 fL

On the end of the vehicle where fixtures would have to be mounted in locations where they could not be maintained to meet the specifications of A-9, an area on each side of the vehicle defined by the height and one-half the width of the vehicle must be lighted. On the other end of the vehicle, specification is the same as A-9.

MACHINE POSITION FOR LIGHT MEASUREMENTS

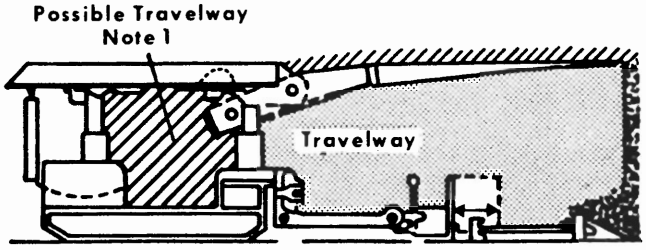
Perpendicular to and between 9 and 10 ft from a relatively smooth coal surface.

ADDITIONAL COMMENTS

On scoops in particular, luminaires at one end of the vehicle must be top-deck mounted to meet specifications. This applies to cases where seam height exceeds frame height by only 6 to 8 in or less. In such event, top-deck mounted fixtures would be unmaintainable.

Lights only need be operated in direction of travel at any given time. Lights may be turned off when they become a glare problem for personnel working on continuous mining machine or loader.

A-11.—All longwall face supports in seam heights greater than or equal to 42 in.



AREAS TO BE ILLUMINATED TO 0.06 fL

The face and all surfaces between the face and the gob side of the travelway.

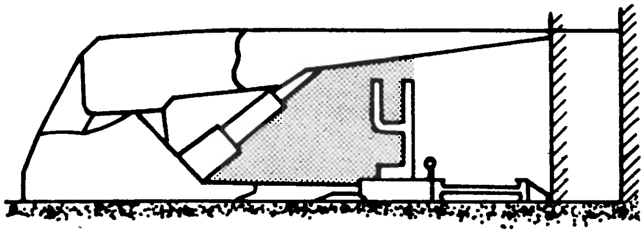
Note 1.—The travelway is the face throughway utilized by personnel for traveling along the face. It is designated by the operator, and such designation must be consistent with actual use. If both throughways are traveled by personnel, both are viewed as travelways and both must be illuminated.

Note 2.—No light measurements are taken on the face conveyor for a distance of 1 ft inby the spillbord. Light transmissions to this portion of the face conveyor would be impractical.

MACHINE POSITION FOR LIGHT MEASUREMENT

Support is pulled forward with roof-canopy tip against the face in its normal position prior to mining.

A-12.—All longwall face supports in seam heights less than 42 in.



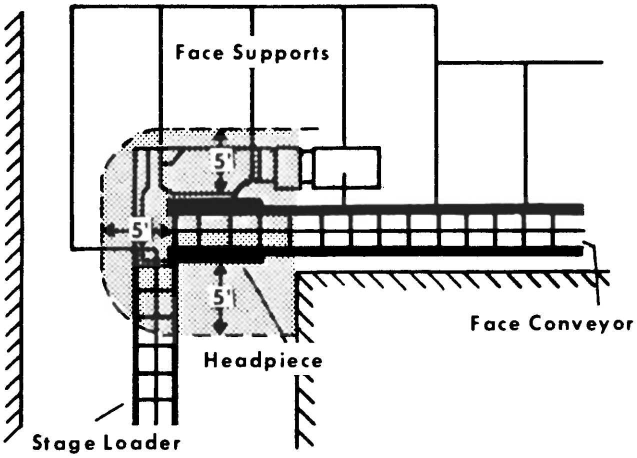
AREAS TO BE ILLUMINATED TO 0.06 fL

Same as A-11 including note 1 except that no light measurements are made inby the spillplate structure. Lack of clearance between the spillplate and roof canopy in low seam heights make light transmission to the face impractical.

MACHINE POSITIONING FOR LIGHT MEASUREMENT

Support is pulled forward with roof-canopy tip against the face in its normal position prior to mining.

A-13.—Longwall conveyor headpiece in all seam heights.



AREAS TO BE ILLUMINATED TO 0.06 fL

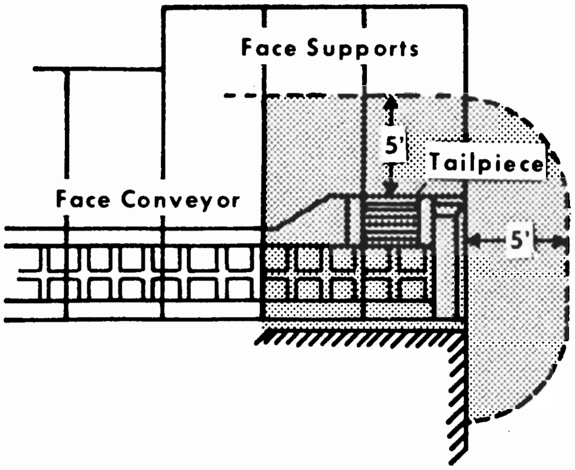
All surfaces within the area defined by a 5-ft perimeter measured horizontally from the face conveyor headpiece in the vicinity where it dumps onto the stage loader (also, see "Additional Comments" section).

ADDITIONAL COMMENTS

Areas upon which shadows are cast by manually set jacks or timbers need not be lighted to 0.06 fL.

Areas in this vicinity obscured by ventilation curtains need not be illuminated to 0.06 fL; however, the curtains must be part of the mine ventilation plan and must be used at all times.

A-14.—Longwall conveyor tailpiece in all seam heights.



AREAS TO BE ILLUMINATED TO 0.06 fL

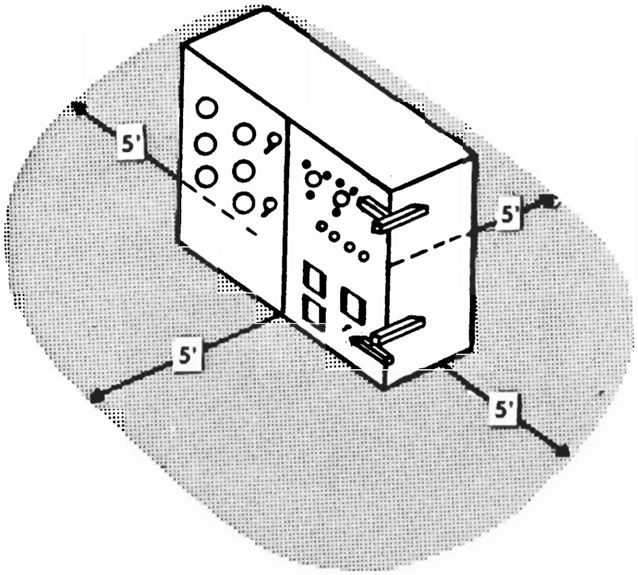
All surfaces within the area defined by a 5-ft perimeter measured horizontally from the face conveyor tailpiece. This distance is measured from the conveyor structure itself, not from drive motors and ancillary equipment.

ADDITIONAL COMMENTS

Areas in this vicinity obscured by ventilation curtains need not be illuminated to 0.06 fL; however, the curtains must be a part of the mine ventilation plan and must be used at all times.

Roof areas upon which shadows are cast by a sideplate (i.e., gobplate) located on the edge of the roof canopy of the last support need not be illuminated to 0.06 fL. This eliminates the necessity of locating a fixture on the side of the roof canopy where, in many mines, it would be subject to mechanical hazard.

A-15.—Longwall control center.



AREAS TO BE ILLUMINATED TO 0.06 fL

All surfaces within the areas defined by a 5-ft perimeter measured horizontally from the edges of the controller box.

ADDITIONAL COMMENTS

Areas upon which shadows are cast by manually set jacks or timbers in the control center area need not be illuminated to 0.06 fL.

APPENDIX B.—SPECIFICATIONS OF AVAILABLE AREA LUMINAIRES AND POWER-CONDITIONING SYSTEMS APPROVED FOR APPLICATION IN UNDERGROUND COAL MINE WORKING PLACES

INTRODUCTION

This appendix presents information on approved area luminaires and power-conditioning systems that are being actively marketed at the time of preparation of this report (several manufacturers declined invitation to include their hardware for lack of an active marketing program). It should prove useful to the user in both identification and comparison of hardware alternatives for a particular application. The discussion in chapter 4 should assist an assessment of this information for making these evaluations.

The information is organized according to manufacturer (in alphabetical order). An initial table identifies the various systems available from the manufacturer for a particular application (machine and power type). A functional description of intrinsically safe, non-incandescent dc, and diesel power-conditioning systems is then provided. Because of general operational similarity, the more routine power-conditioning systems, core-and-coil ballasts, and resistors are not described in detail. Component differences, however, may significantly affect performance of these systems and one should consult the manufacturers for details on their specifications. Subsequently, luminaire specifications are tabularized and representative photographs of these luminaires are provided. The final section of the appendix presents description of the power-conditioning systems and connection requirements for the various lighting systems utilized in longwall application.

Table B-1.—Joy Manufacturing Co. system alternatives

Application	XP or IS	Ballasts				Lamp type	Model	Description
		Standard	Solid state	Integral	Remote			
MFE, ac	XP	X			X	VHO fl	500131-33 500131-35	None.

fl Fluorescent.
IS Intrinsically safe.
MFE Mine face equipment.
XP Explosion-proof.

NOTE.—No entry in a ballast column indicates the category is not applicable.

Table B-2.—Joy Manufacturing Co. luminaire specifications

	Model	
	500131-33	500131-35
Lamp:		
Type	fl	fl.
Number	1	1.
Designation	F24T12/CW/SHO	F18T12/CW/SHO.
Circuit design:		
Internal to luminaire	XP	XP.
Leads to luminaire	XP	XP.
Guard standard	Yes	Yes.
Dimensional (with guard), in:		
Height	4-1/4	4-1/4.
Width	5-1/2	5-1/2.
Length	30-1/8	24-1/8.
Weight (with guard) lb	32	28.
Materials:		
Lens	Polycarbonate	Polycarbonate.
Housing	Steel	Steel.
Guard	..do	Do.
Integral ballast	No	No.
Packing glands:		
Single or dual	Single	Single
Threaded or slip-fit	Threaded	Threaded.
Clamp or tubing	Clamp	Clamp.
Connection integral to luminaire	No	No.
Pigtail integral to luminaire.	No	No.
Separate XP connector supplied	No	No.
Lamp cartridge:		
Utilized	Yes	Yes.
Connection type	Wirenut	Wirenut.
Primary application	MFE	MFE.
Ac or dc machine power	ac	ac.
Figure	B-1	B-1.

CW Cool White.
fl Fluorescent.
MFE Mine face equipment.
SHO Super-high output.
XP Explosion-proof.

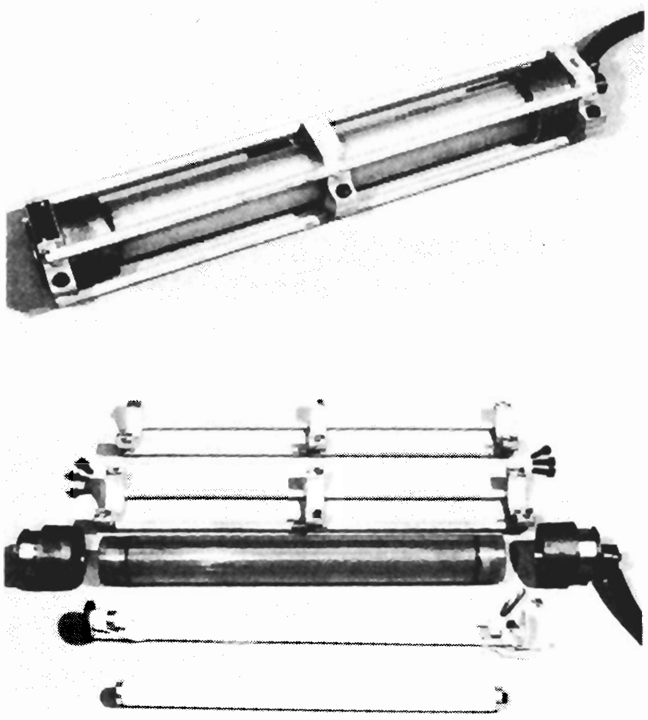


Figure B-1.—Joy Manufacturing Co. model 500131-33 and 500131-35 luminaires.

Table B-3.—McJunkin Corp. system alternatives

Application	XP or IS	Ballasts				Lamp type	Model	Description
		Standard	Solid state	Integral	Remote			
MFE, ac	XP	X			X	VHO fl	100/64	None.
MFE, ac	XP	X		X		Standard fl	100/30 100/15 100/6	Do.
MFE, ac	XP					inc	400-A/S	Do.
						Tubular inc	100/6 inc	Do.
MFE, dc	XP		X		X	VHO fl	100/64	(1)
MFE, dc	XP		X		X	HPS	400-A/S	(1)
MFE, dc	XP					inc	400-A/S	None.
						Tubular inc	100/6 inc	Do.
MFE, diesel	XP		X		X	VHO fl	100/64	(2)
MFE, diesel	XP		X		X	HPS	400-A/S	(2)
Longwall	XP	X		X		Standard fl	100/30H 100/15H 100/6H	None.

fl	Fluorescent.	IS	Intrinsically safe.	XP	Explosion-proof.
HPS	High-pressure sodium.	MFE	Mine face equipment.		
inc	Incandescent.	VHO	Very-high output.		

[1] Solid-state inverter ballasts are used to invert dc machine power to a high-frequency lamp drive power. Drop resistors are used to reduce machine voltage to a level appropriate for the ballasts and an extensive transient suppression package (chokes, capacitors, and voltage trap resistors) is utilized to protect the system.

[2] Similar to dc power systems, uses solid-state inverter ballasts on diesel equipment lighting systems. Dc power is provided by a hydraulically driven generator with provision for flow control to maintain a constant voltage level with varying engine speed.

NOTE.—No entry in a ballast column indicates the category is not applicable.

Table B-4.—McJunkin Corp. luminaire specifications

	Model					
	100/6	400-A, 400-S	100/64	100/30H	100/15, 100/15H	100/6, 100/6H
Lamp:						
Type	inc	inc, HPS	fl	fl	fl	fl.
Number	1	1	1	1	1	1.
Designation	25 W T10 clear.	150 W MV 70 or 150 W HPS.	F24T12CW/ SHOII.	F30T8/CW	F15T8/CW	F6T5CW.
Circuit design:						
Internal to luminaire	XP	XP	XP	XP	XP	XP.
Leads to luminaire	XP	XP	XP	XP	XP	XP.
Guard standard	Yes	No	Yes	Yes	Yes	Yes.
Optional guard available	NAp	No	NAp	NAp	NAp	NAp.
Dimensions (with guard), in:						
Height	3	6-1/2	3-1/2	3	3-1/2	3.
Width	5	9	4-1/2	5	4-1/2	5.
Length	15-3/4	13-1/2	28-1/2	49-1/2	28-1/2	15-3/4.
Weight (with guard) lb	5	[1]22, [2]53	10	20	10	5.
Materials:						
Lens	Lexan	Tempered glass	Lexan	Lexan	Lexan	Lexan.
Housing	Steel	Steel	Steel	Steel	Steel	Steel.
Guard	do	NAp	do	do	do	Do.
Integral ballast	No	No	No	Yes	Yes	Yes.
Ballast:						
Solid state	NAp	NAp	NAp	No	No	No.
Core and coil	NAp	NAp	NAp	Yes	Yes	Yes.
Input voltage . . . V ac	NAp	NAp	NAp	120	120	120.
Potted	NAp	NAp	NAp	No	No	No.
Packing glands:						
Single or dual	Dual	Single	Dual	Dual	Dual	Dual.
Threaded or slip-fit	Threaded	Threaded	Threaded	Threaded	Threaded	Threaded.
Clamp or tubing	Tubing	Tubing	Tubing	Tubing	Tubing	Tubing.
Connection integral to luminaire.	No	No	No	No	No	No.
Pigtail integral to luminaire.	No	No	No	No	No	No.
Separate XP connector supplied.	No	No	No	Yes	Yes, 15H.	Yes, 6H.
Lamp cartridge:						
Utilized	NAp	No	Yes	Yes	Yes	Yes.
Connection type	NAp	NAp	Spade terminal	Spade terminal	Spade terminal	Spade terminal.
Primary application	MFE	MFE	MFE	Longwall	MFE, 15; longwall, 15H	MFE, 6; longwall, 6H.
Ac or dc machine power	Both	Both	Both	ac	ac	ac.
Figure	B-3	B-4	B-2	B-3	B-3	B-3.

CW	Cool white.	MFE	Mine face equipment.	XP	Explosion-proof.
inc	Incandescent.	MV	Mercury vapor.	[1] Aluminum.	
fl	Fluorescent.	NAp	Not applicable.	[2] Steel.	
HPS	High-pressurization.	SHO	Super-high output.		

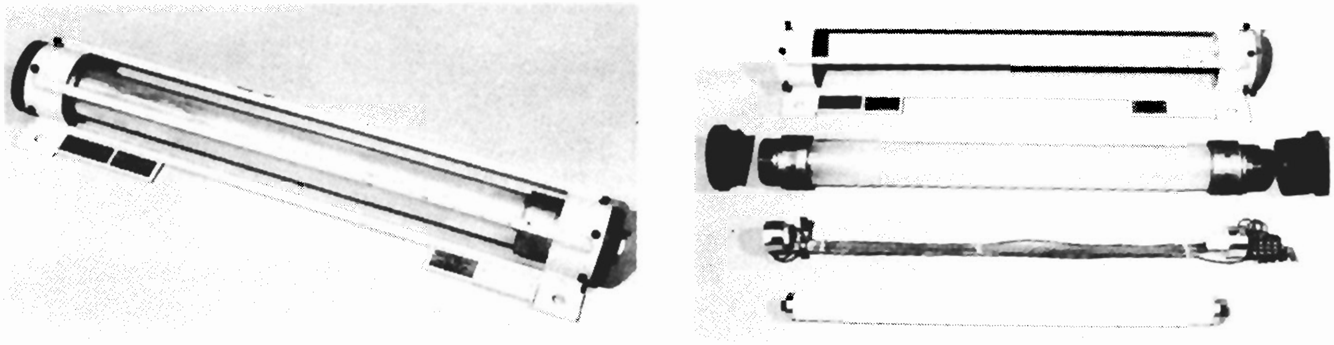


Figure B-2.—McJunkin Corp. model 100/64 luminaire.

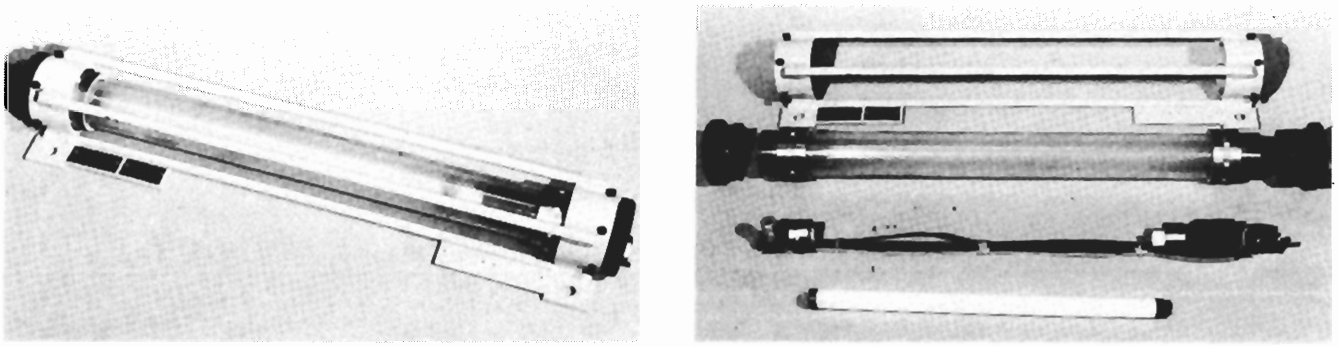


Figure B-3.—McJunkin Corp. model 100/30H, 100/15, and 100/6 luminaires.

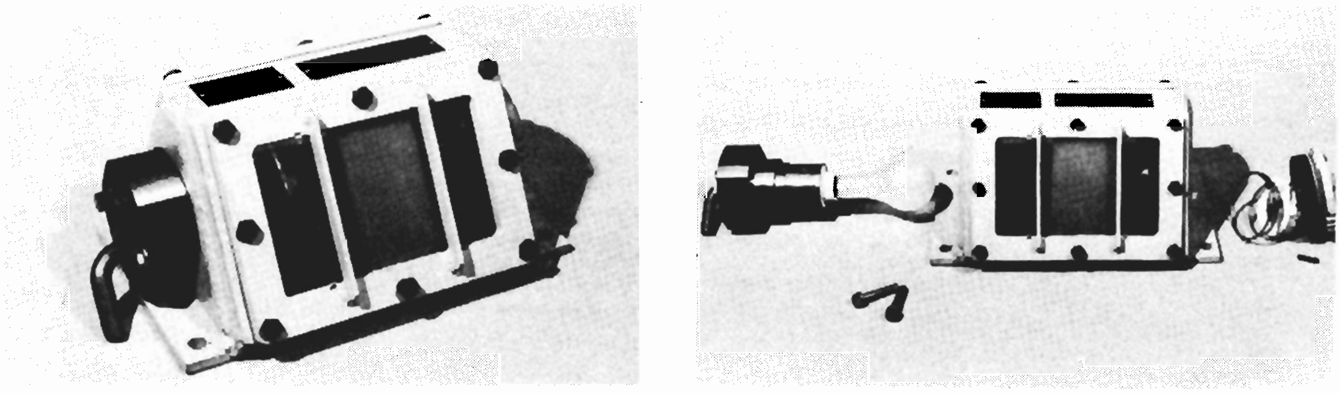


Figure B-4.—McJunkin Corp. model 400-A and 400-S luminaires.

Table B-5.—Mine Safety Appliances Co. system alternatives

Application	XP or IS	Ballasts: Standard	Solid state	Integral	Remote	Lamp type	Model	Description
MFE, ac	XP		X	X		HO fl	LX2401	None.
MFE, dc	XP		X	X		HO fl	LX2401	(1)
Longwall	XP		X	X		HO fl	LX2401	None.

fl Fluorescent. IS Intrinsically safe. XP Explosion-proof.
HO High output. MFE Mine face equipment.

[1] Resistors are used to drop machine voltage to a level suitable for the solid-state inverter ballasts integral to the luminaire. The ballasts are protected from voltage spikes by a zener diode.

NOTE.—No entry in a ballast column indicates the category is not applicable.

Table B-6.—Mine Safety Appliances Co. luminaire specifications

	Model LX2401
Lamp:	
Type	fl.
Number	1.
Designation	F24T12/CW/HO.
Circuit design:	
Internal to luminaire	XP.
Leads to luminaire	XP.
Guard standard	Yes.
Dimensions (with guard), in:	
Height	4-1/2.
Width	4-1/2.
Length	33.
Weight (with guard) . . . . . . lb	[1]24, [2]13.
Materials:	
Lens	Polycarbonate.
Housing	Steel, aluminum, malleable iron.
Guard	Steel.
Integral ballast	Yes.
Ballast:	
Solid state	Yes.
Core and coil	No.
Ballast—Continued	
Input voltage	120 ac, 130 dc, 300 dc.
Potted	Yes.
Packing glands:	
Single or dual	Dual.
Threaded or slip-fit	Threaded.
Clamp or tubing	Tubing.
Connection integral to luminaire.	No.
Pigtail integral to luminaire.	No.
Separate XP connector supplied.	Yes.
Lamp cartridge:	
Utilized	Yes.
Connection type	Plug.
Primary application	MFE and longwall.
Ac or dc machine power	Both.
Figure	B-5.

CW Cool white.
fl Fluorescent.
HO High output.
MFE Mine face equipment.
XP Explosion-proof.

[1] Steel.

[2] Aluminum.

Table B-7.—Mining Controls Inc. system alternatives

Application	XP or IS	Ballasts: Standard	Ballasts: Solid state	Ballasts: Integral	Ballasts: Remote	Lamp type	Model	Description
MFE, ac	XP					inc.	21322	None.
MFE, ac	XP					Tungsten-halogen.[1]	NAp	Do.
MFE, dc	XP					. . do	NAp	Do.
MFE, dc	XP					. . do	NAp	Do.

IS Intrinsically safe.
MFE Mine face equipment.
XP Explosion-proof.

[1] See figure B-7.

NOTE.—No entry in a ballast column indicates the category is not applicable.

Table B-8.—Mining Controls Inc. luminaire specifications

	Model 21322
Lamp:	
Type	inc.
Number	1.
Designation	150 W.
Circuit design:	
Internal to luminaire	XP.
Leads to luminaire	XP.
Guard standard	No.
Optional guard available	Yes.
Dimensions, in:	
With guard:	
Height	[1]7-1/4, [2]8-1/4.
Width	[1]7-1/2, [2]7.
Length	[1]12, [2]16.
Without guard:	
Height	6-1/4.
Width	6-1/4.
Length	12.
Weight, lb:	
With guard	[1]34, [2]39.
Without guard	[3]21, [4]45, [5]39.
Materials:	
Lens	Tempered glass.
Housing	Aluminum, brass, ductile iron.
Guard	Steel.
Integral ballast	No.
Packing glands:	
Single or dual	Dual.
Threaded or slip-fit	Threaded.
Clamp or tubing	Tubing.
Connection integral to luminaire.	No.
Pigtail integral to luminaire.	No.
Separate XP connector supplied.	No.
Lamp cartridge:	
Utilized	No.
Connection type	NAp.
Primary application	MFE and longwall.
Ac or dc machine power	Both.
Figure	B-6.

inc Incandescent.
MFE Mine face equipment.
NAp Not applicable.
XP Explosion-proof.

[1] Standard.

[2] Heavy duty.

[3] Aluminum.

[4] Brass.

[5] Ductile iron.

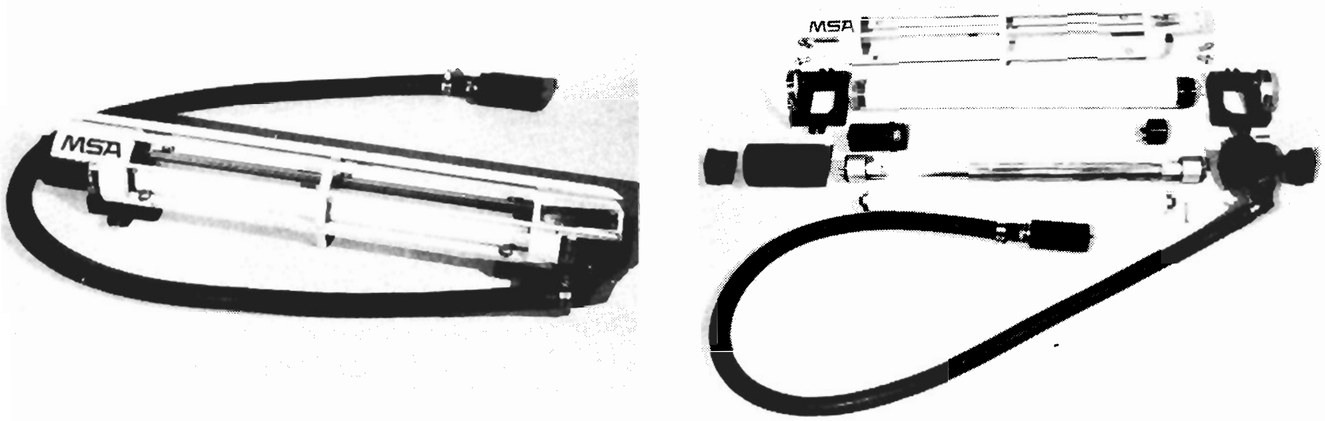


Figure B-5.—Mine Safety Appliances Co. model LX2401 luminaire.

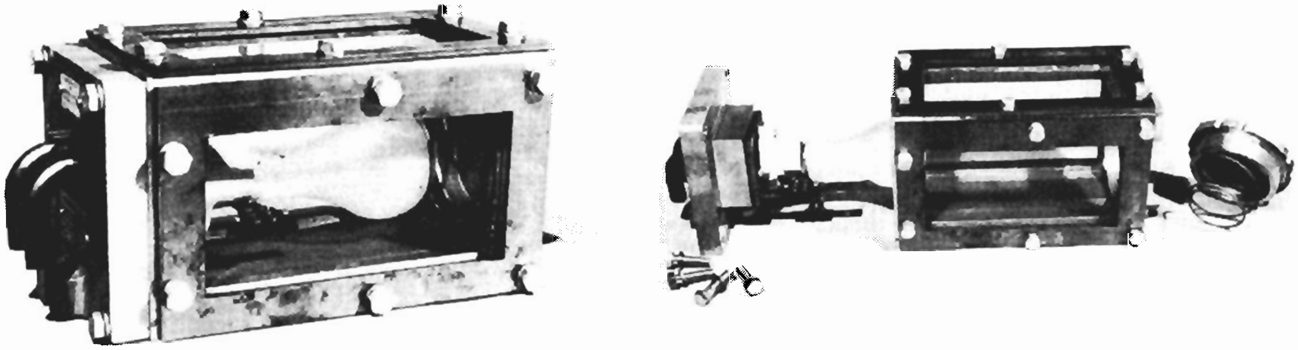


Figure B-6.—Mining Controls Inc. model 21322 luminaire.

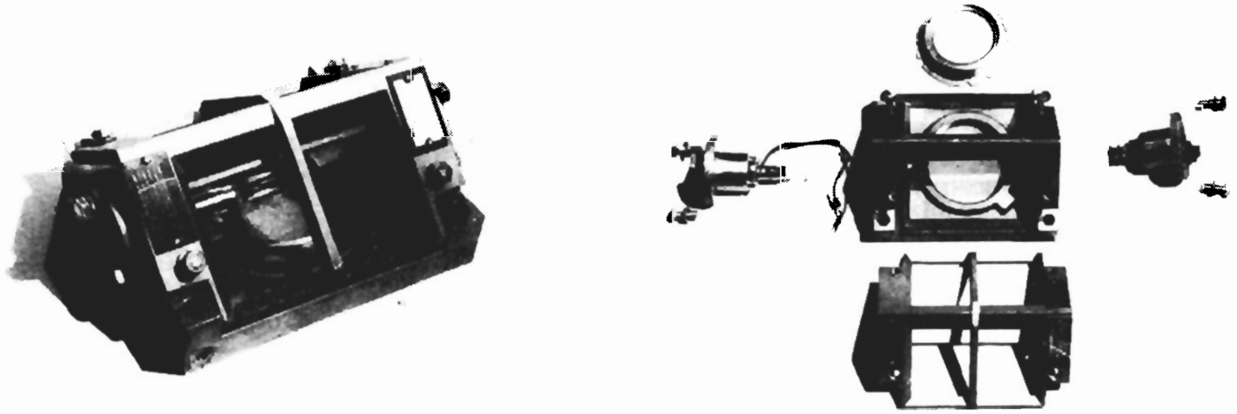


Figure B-7.—Mining Controls Inc. tungsten-halogen luminaire.

Table B-9.—National Mine Service Co. system alternatives

Application	XP or IS	Ballasts: Standard	Ballasts: Solid state	Ballasts: Integral	Ballasts: Remote	Lamp type	Model	Description
MFE, ac	XP	X			X	HO fl	5401-0012/0111 5401-0004/0103	None.
MFE, ac	XP		X	X		Standard fl	5401-0202/0293 5402-0995	Do.
MFE, dc	XP		X		X	HO fl	5401-0012/0111 5401-0004/0130	(1)
Longwall	XP		X	X		Standard fl	5401-0202/0293 5402-0995	None.

fl Fluorescent. IS Intrinsically safe. XP Explosion-proof.
HO High output. MFE Mine face equipment.

[1] Dc power supplies use remotely mounted inverter ballasts to drive the lamp. A switching regulator unit called a "preregulator 120 dc" accepts machine power over a 200- to 600-V dc range and reduces or regulates it to 120 V dc for the inverter ballasts. The preregulator also has provision for transient protection.

NOTE.—No entry in a ballast column indicates the category is not applicable.

Table B-10.—National Mine Service Co. luminaire specifications

	Model			
	[1]5401-0012, [2]5401-0111	[1]5401-0004, [2]5401-0103	[1]5401-0202, [3]5401-0293	5402-0995
Lamp:				
Type	fl	fl	fl	fl.
Number	1	1	1	2.
Designation	F24T12/CW/HO	F18T12/CW/HO	F24T12/CW	None.
Circuit design:				
Internal to luminaire	XP	XP	XP	XP.
Leads to luminaire	XP	XP	XP	XP.
Guard standard	No	No	No	No.
Optional guard available	Yes	Yes	Yes	Yes.
Dimensions, in:				
With guard:				
Height	4-1/2	4-1/2	4-1/2	4.
Width	5-3/8	5-3/8	5-3/8	10-3/4.
Length	29-3/4	23-3/4	32	12.
Without guard:				
Height	3-1/2	3-1/2	3-1/2	3.
Width	5	5	5	10.
Length	29-3/4	23-3/4	32	12.
Weight, lb:				
With guard	[1]16-1/2, [2]18-1/2.	[1]15-3/4, [2]17-3/4.	[1]22, [3]24	30-1/2.
Without guard	10	11-1/4	[1]15-1/2, [3]17-1/2.	25-1/2.
Materials:				
Lens	Polycarbonate	Polycarbonate	Polycarbonate	Tempered glass.
Housing	Aluminum	Aluminum	Aluminum	Ductile cast iron.
Guard	Steel weldment	Steel weldment	Steel weldment	Steel-polycarbonate.
Integral ballast	No	No	Yes	Yes.
Ballast:				
Solid state	NAp	NAp	Yes	No.
Core and coil	NAp	NAp	No	Yes.
Input voltage V ac	NAp	NAp	117	117.
Potted	NAp	NAp	Yes	Yes.
Packing glands:				
Single or dual	Single	Single	Single	Dual.
Threaded or slip-fit	Threaded	Threaded	Threaded	Threaded.
Clamp or tubing	Clamp	Clamp	Clamp	Tubing.
Connection integral to luminaire	No	No	No	No.
Pigtail integral to luminaire	No	No	No	No.
Separate XP connector supplied	No	No	Yes	No.
Lamp cartridge:				
Utilized	Yes	Yes	Yes	No.
Connection type	Wirenut	Wirenut	Wirenut	NAP.
Primary application	MFE	MFE	MFE and longwall	MFE and longwall.
Ac or dc machine power	Both	Both	ac	ac.
Figure	B-8	B-8	B-9	B-10.

CW Cool white. HO High output. XP Explosion-proof. [2]Brass.
fl Fluorescent. NAp Not applicable. [1]Aluminum. [3]Bronze.

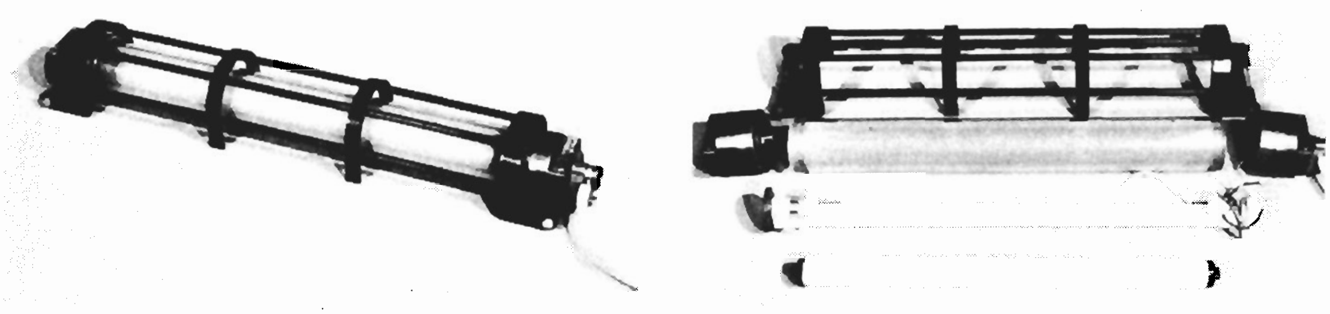


Figure B-8.—National Mine Service Co. model 5401-0012, 5401-0111, 5401-0004, and 5401-0103 luminaires.

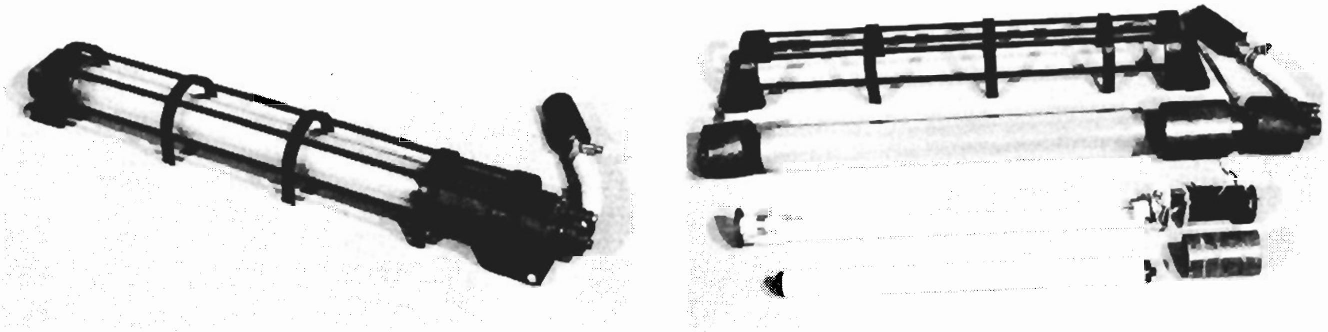


Figure B-9.—National Mine Service Co. model 5401-0202 and 5401-0293 luminaires.

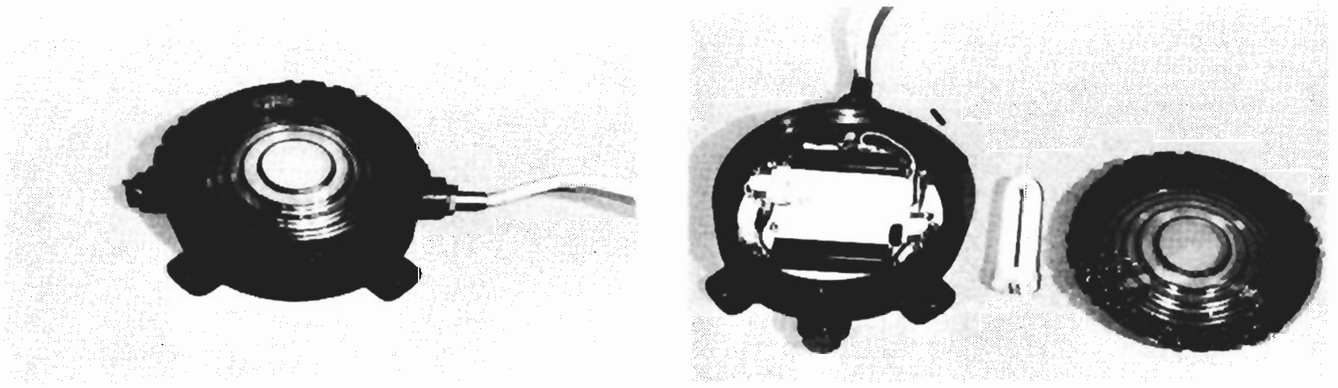


Figure B-10.—National Mine Service Co. model 5402-0995 luminaire.

Table B-11.—Ocenco Inc. system alternatives

Application	XP or IS	Ballasts: Standard	Ballasts: Solid state	Ballasts: Integral	Ballasts: Remote	Lamp type	Model	Description.
MFE, ac	IS[1]		X	X		Standard fl	30M 15/3M 16M	(2)
MFE, ac	XP					inc	AR-150 30M	None.
MFE, dc	IS[1]		X	X		Standard fl	15/3M 16M	(3)
MFE, dc	XP					inc	AR-150 30M	None. (2)
MFE, diesel	XP		X	X		Standard fl	15/3M 16M 30M	(4) None.
Longwall	IS[1]		X	X		Standard fl	15/3M 16M	(4)

fl Fluorescent.
inc Incandescent.
IS Intrinsically safe.
MFE Mine face equipment.
XP Explosion-proof.

[1] Cabling only, luminaires are explosion-proof.

[2] Power supply transforms machine power to 25 to 30 V ac and subsequently conditions this power to 13 to 16 V dc by a solid-state filter-rectifier unit. This power is distributed through 2 solid-state control circuits (channels), which provide intrinsically safe 12-V dc power to integral, inverter-ballasted luminaries. Each control channel incorporates redundant circuits to limit output power to 12 V per 100 A, including an electronic current limiter, overvoltage crowbar circuit, and output fusing. The current limit restricts the number of luminaires that can be connected to each distribution channel.

[3] Power supply utilizes the same control circuitry as ac power supply. Machine power is inverted to high-frequency ac power, transformed to 12 to 16 V ac, then inverted to dc power for the control channels. A transient suppressor unit protects the power-conditioning system. Resistors are installed to maintain system input voltage at the lower end of the design range for the system and the transient supressor is designed to suppress voltage peaks above the upper end of the voltage design range.

[4] Ac power supply is utilized with power obtained from a hydraulically driven alternator with provision for flow control to maintain constant voltage for variation in engine rotational speed.

NOTE:—No entry in a ballast column indicates the category is not applicable.

Table B-12.—Ocenco Inc. luminaire specifications

	Model: 30M	15/3M	16M	AR-150
Lamp:				
Type	fl	fl	fl	inc.
Number	1	1	2	1.
Designation	F30T12	F15T12	F8T5	150 W A-23 or PS-25.
Circuit design:				
Internal to luminaire	XP	XP	XP	XP.
Leads to luminaire	IS	IS	IS	XP.
Guard standard	No	No	No	No.
Optional guard available	Yes	Yes	Yes	Special order.
Dimensions, in:				
With guard:				
Height	5	5	5	NAp.
Width	6	6	6	NAp.
Length	40	28	16	NAp.
Without guard:				
Height	3	3	3	6.
Width	3	3	3	9-1/2.
Length	40	28	14	10-1/2.
Weight, lb:				
With guard	33	27	9	NAp.
Without guard	8	7	4	40.
Materials:				
Lens	Polycarbonate.	Polycarbonate.	Polycarbonate.	Tempered glass.
Housing	do	do	do	Steel.
Guard	Steel	Steel	Steel	NAp.
Integral ballast	Yes	Yes	Yes	No.
Ballast:				
Solid state	Yes	Yes	Yes	NAp.
Core and coil	No	No	No	NAp.
Input voltage V dc	12	12	12	NAp.
Potted	Yes	Yes	No	NAp.
Packing glands:				
Single or dual	NAp	NAp	NAp	Dual.
Threaded or slip-fit	NAp	NAp	NAp	Threaded.
Clamp or tubing	NAp	NAp	NAp	Tubing.
Connection integral to luminaire.	No	No	No	No.
Pigtail integral to luminaire.	Yes	Yes	Yes	No.
Separate XP connector supplied	No	No	No	No.
Lamp cartridge:				
Utilized	No	No	Yes	No.
Connection type	NAp	NAp	Plug	NAP.
Primary application	MFE and longwall.	MFE and longwall.	MFE and longwall.	MFE.
Ac or dc machine power	Both	Both	Both	Both.
Figure	B-11	B-11	B-12	B-13.

fl Fluorescent.
inc Incandescent.
IS Intrinsically safe.
NAp Not applicable.
XP Explosion-proof.

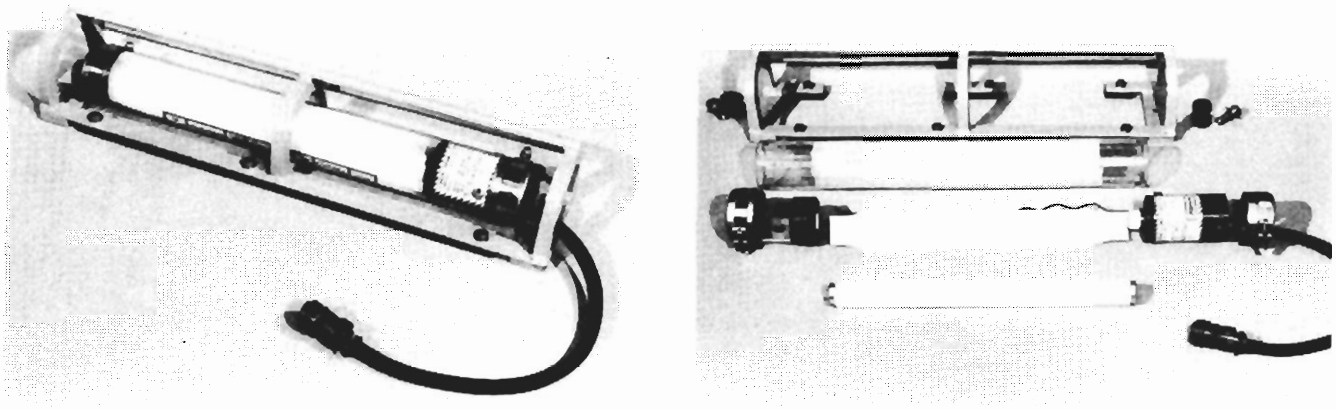


Figure B-11.—Ocenco Inc. model 30M and 15/3M luminaires.

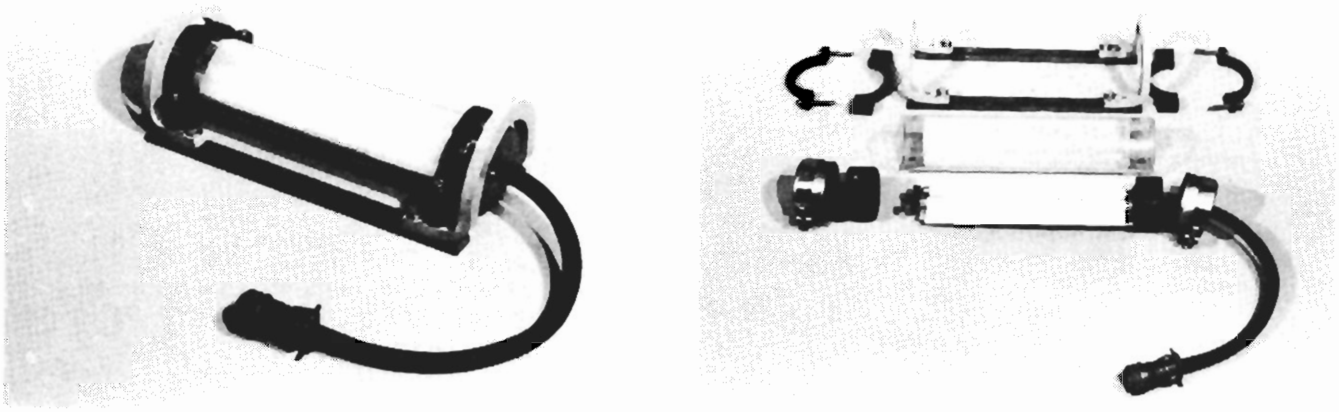


Figure B-12.—Ocenco Inc. model 16M luminaire.

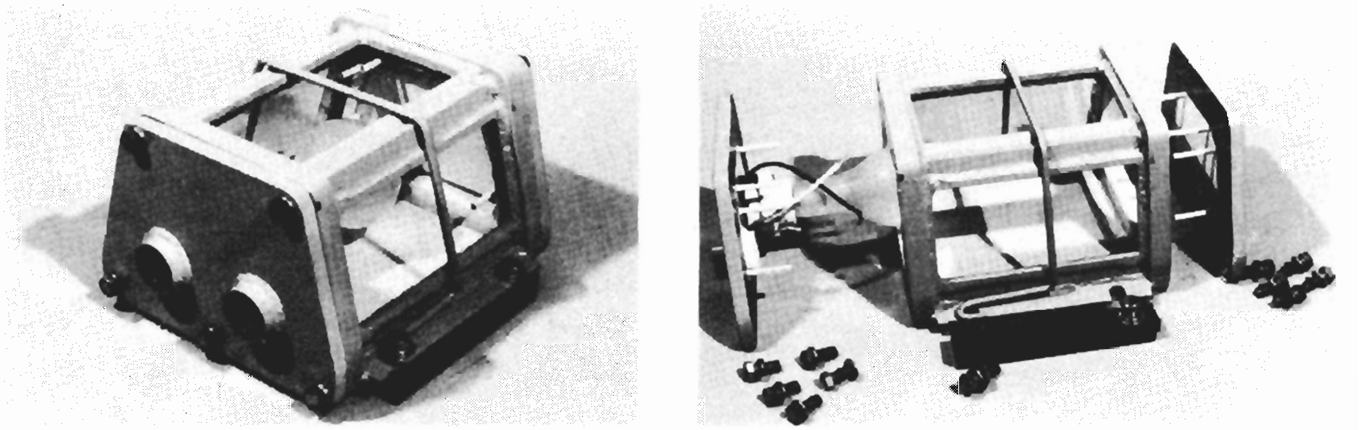


Figure B-13.—Ocenco Inc. model AR-150 luminaire.

Table B-13.—Service Machine Co. system alternatives

Application	XP or IS	Ballasts				Lamp type	Model	Description
		Standard	Solid state	Integral	Remote			
Longwall	IS		X		X	Standard fl	D513	(1)

fl Fluorescent. IS Intrinsically safe. XP Explosion-proof.

[1] Main power is rectified and fed to inverter ballasts housed within the power supply enclosure, which provides an intrinsically safe high-frequency lamp drive that is distributed to the luminaires (2 lamps per remote ballast). Both cabling and luminaires are intrinsically safe.

NOTE.—No entry in a ballast column indicates the category is not applicable.

Table B-14.—Service Machine Co. luminaire specifications

	Model D513
Lamp:	
Type	fl.
Number	1.
Designation	F13T5/CW.
Circuit design:	
Internal to luminaire	IS.
Leads to luminaire	IS.
Guard standard	No.
Optional guard available	No.
Dimensions (without guard), in:	
Height	2-3/16.
Width	2-5/8.
Length	26-1/4.
Weight (without guard) . . . . . . lb	3-1/2.
Materials:	
Lens	Polycarbonate.
Housing	Steel, brass, stainless steel.

	Model D513
Integral ballast	No.
Packing glands:	
Single or dual	NAp.
Threaded or slip-fit	NAp.
Clamp or tubing	NAp.
Connection integral to luminaire.	Yes.
Pigtail integral to luminaire.	No.
Separate XP connector supplied.	No.
Lamp cartridge:	
Utilized	No.
Connection type	NAp.
Primary application	Longwall.
Ac or dc machine power	ac.
Figure	B-14.

CW Cool white. IS Intrinsically safe. NAp Not applicable.
fl Fluorescent. MFE Mine face equipment.

Table B-15.—West Virginia Armature Co. system alternatives

Application	XP or IS	Ballasts				Lamp type	Model	Description
		Standard	Solid state	Integral	Remote			
MFE, ac	XP	X			X	VHO fl	18400-24 18400-18	None.
MFE, ac	XP	X			X	HPS	14812D	Do.
MFE, ac	XP					inc	14812D	Do.
MFE, dc	XP					inc	14812D	Do.

fl Fluorescent. IS Intrinsically safe. XP Explosion-proof.
HPS High-pressure sodium. MFE Mine face equipment.
inc Incandescent. VHO Very-high output.

NOTE.—No entry in a ballast column indicates the category is not applicable.

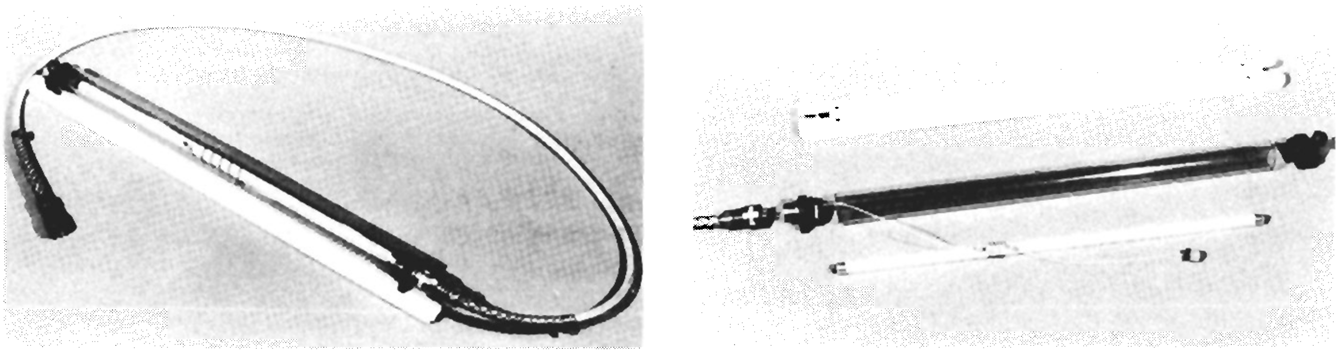


Figure B-14.—Service Machine Co. model D513 luminaire.

Table B-16.—West Virginia Armature Co. luminaire specifications

	Model		
	18400-24	18400-18	14812D
Lamp:			
Type	fl	fl	inc or HPS.
Number	1	1	1.
Designation	F24T12/CW/SHO.	F18T12/CW/SHO.	100 W HPS, 150 W inc.
Circuit design:			
Internal to luminaire	XP	XP	XP.
Leads to luminaire	XP	XP	XP.
Guard standard	Yes	Yes	No.
Optional guard available	NAp	NAp	Yes.
Dimensions (with guard), in:			
Height	3-3/4	3-3/4	5-3/4.
Width	3-3/4	3-3/4	5-3/4.
Length	31-1/4	25-1/4	13-1/4.
Weight (with guard) . . . . lb	29	27	[1]45, [2]25.
Materials:			
Lens	Polycarbonate.	Polycarbonate.	Tempered glass.
Housing	Steel and brass	Steel and brass	Steel or aluminum.
Guard	Steel	Steel	Steel.
Integral ballast	No	No	No.
Packing glands:			
Single or dual	Single	Single	Dual.
Threaded or slip-fit	Threaded	Threaded	Threaded.
Clamp or tubing	Tubing	Tubing	Tubing.
Connection integral to luminaire.	No	No	No.
Pigtail integral to luminaire.	No	No	No.
Separate XP connector supplied.	No	No	No.
Lamp cartridge:			
Utilized	Yes	Yes	No.
Connection type	Plug	Plug	NAp.
Primary application	MFE	MFE	MFE.
Ac or dc machine power	ac	ac	ac, HPS; both, inc.
Figure	B-15	B-15	B-16.

fl Fluorescent.
HSP High-pressure sodium.
inc Incandescent.
NAp Not applicable.
XP Explosion-proof.

[1] Iron.

[2] Aluminum

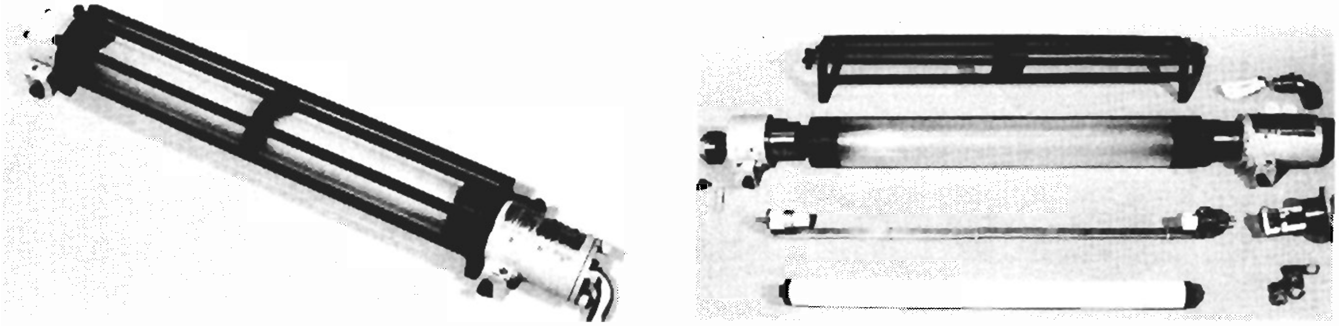


Figure B-15.—West Virginia Armature Co. model 18400-24 and 18400-18 luminaires.

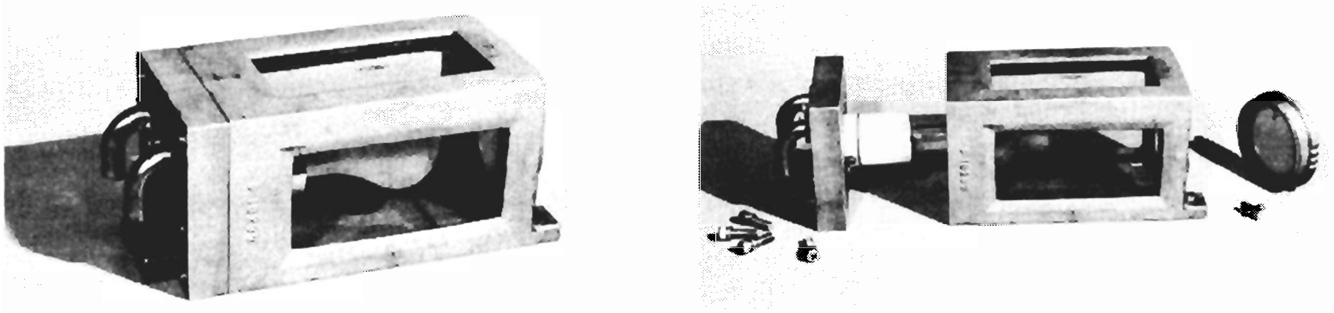


Figure B-16.—West Virginia Armature Co. model 14812D luminaire.

LONGWALL ILLUMINATION SYSTEMS

Important descriptive information is presented below for the various illumination systems approved for use on longwalls. Figures B-17 and B-18 show a "typical" layout and interconnections for each of the manufacturer's systems. As indicated in the figures, all systems utilize a power center (typically a transformer with overcurrent, short circuit, and ground fault protection, along with ground monitoring) to provide 120-V, three-phase ac power for distribution along the face. The 120-V, three-phase power is connected to intermediate power-conditioning or distribution units that subsequently deliver power to the luminaires. As outlined in chapter 4, system interconnection is important on longwall lighting systems. With respect to the power supply or distribution box, there are three basic categories utilized on these systems, as follows:

1. Separate cable to each luminaire with intermediate connector(s).
2. Cable is feed-through connected to string of dual-glanded luminaires. Intermediate connectors utilized.
3. Junction boxes are installed on the feeder line for each luminaire. A cable with line-installed connector runs from each junction box to each luminaire.

A functional description of four of the manufacturer's systems follows:

Ocenco (fig. B-17).—The main power is transformed, rectified, and filtered to 13 to 16 V dc, which is fed to each of two identical control circuits or channels that provide intrinsically safe 12-V dc power to the luminaires. Each channel limits power output to 12 V at 10 A and insures that intrinsically safe conditions are maintained in the event of failure. The current limit restricts the number of lamps that may be driven to 10 integrally ballasted model 15/3M or 8 model 30 luminaires per power conditioning unit. Type 3 interconnection is utilized between the power supplies and luminaires.

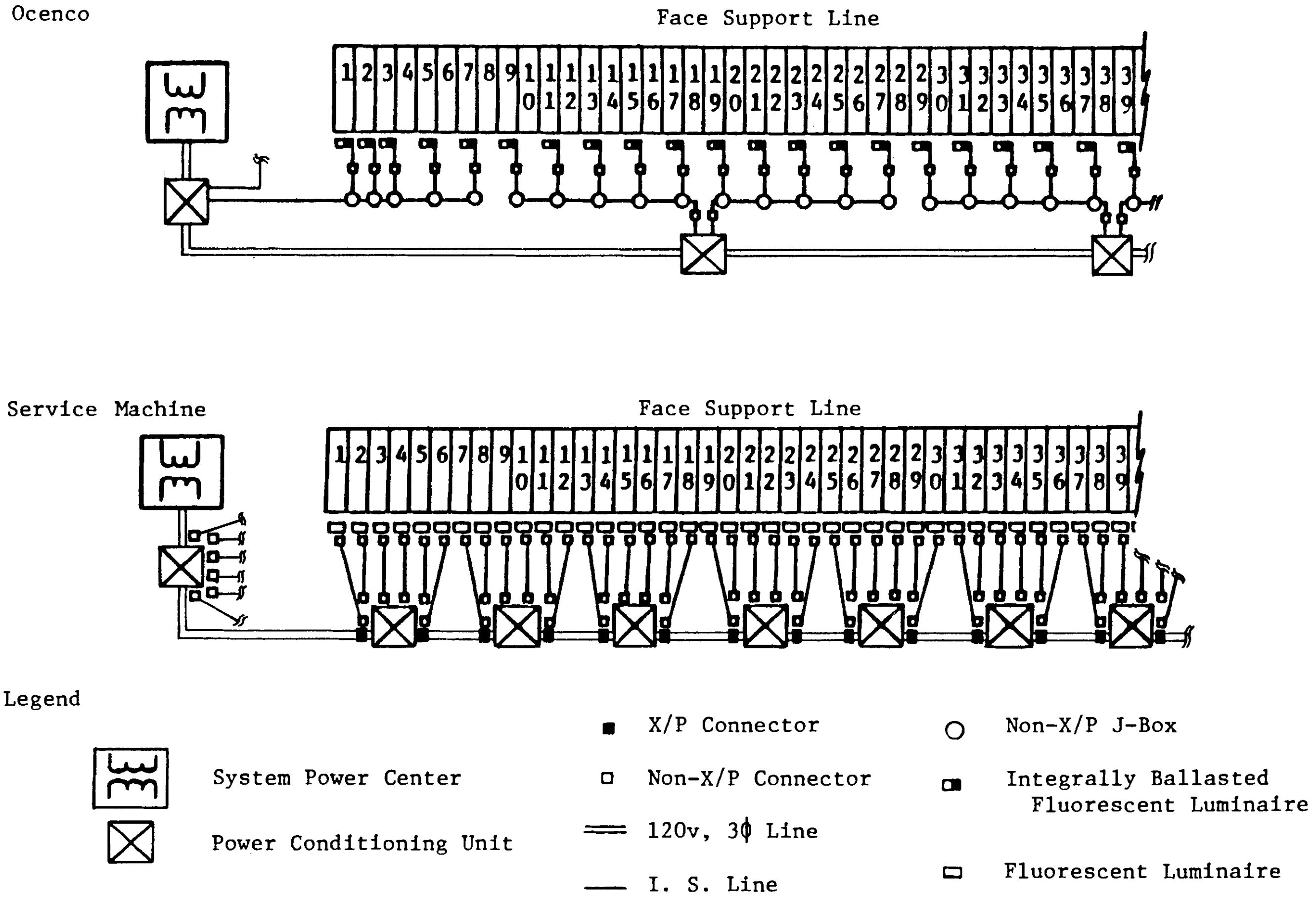


Figure B-17.—Installation and wiring schematics for intrinsically safe fluorescent systems on a typical coal mine longwall face.

McJunkin (*fig. B-18*).—To maintain load balance, distribution units are connected across alternate phases of the main feed-through line. Two 120-V, single-phase feeder lines originate at the distribution box and provide power for up to 10 feed-through model integrally ballasted 100/30 luminaires per line, or a maximum of 20 lamps per distribution unit. An intrinsically safe interlock unit is provided for connector deadfacing and ground-fault protection. To offset line losses, an autotransformer voltage boost is used in distribution units distant from the system power center. Type 2 interconnection is utilized between the distribution boxes and luminaires.

Mine Safety Appliances (*fig. B-18*).—Two branch feed lines originate at the distribution unit by connecting across phases of the main feed-through and provide 120-V, single-phase power to a maximum of 12 feed-through model LX2401 luminaires per line for a maximum of 24 per distribution unit. To maintain load balance, the branch phase connections alternate between phases along the face. A different unit with a pilot system is provided for meeting the Commonwealth of Pennsylvania deadfacing requirements. Type 2 interconnection is utilized between the distribution boxes and luminaires.

National Mine Service (*fig. B-18*).—Distribution units are connected across alternate phases of the main feed-through line. Five feeder lines originate at each distribution box with each line supplying 120 V, single-phase power to a single luminaire for a total of five luminaires per distribution unit. Three different distribution units are available, providing options concerning pilot circuit configurations. One unit provides no provision for a pilot circuit and basically consists of a terminal board in an explosion-proof enclosure. A second unit provides a pilot circuit to each luminaire with a single relay at the distribution box. The third option provides a separate pilot circuit and relay for each luminaire, enabling decoupling of one luminaire while maintaining the operation of the remaining luminaires on the distribution unit. Type 1 interconnection is utilized between the distribution boxes and luminaires.

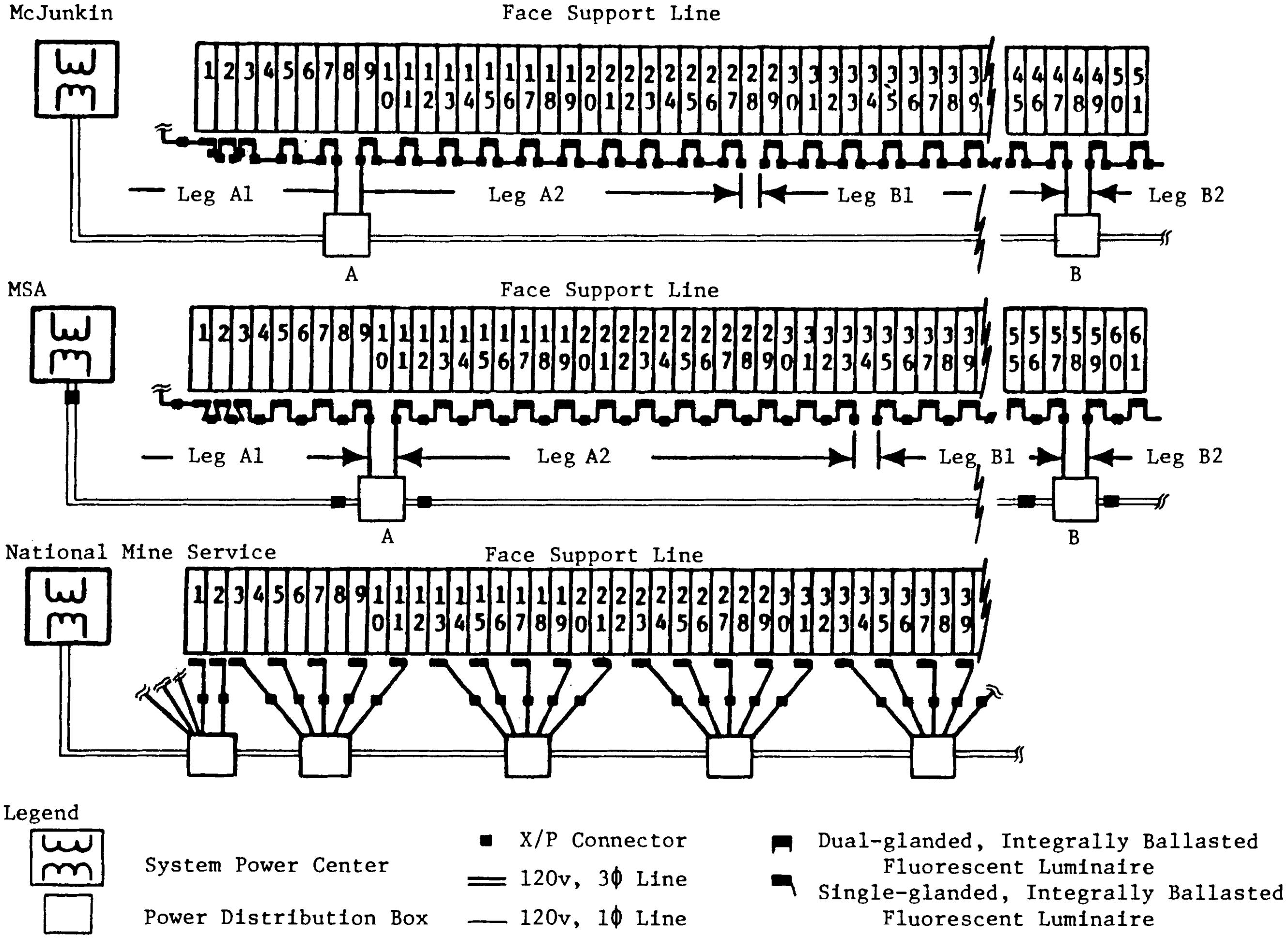


Figure B-18.—Installation and wiring schematics for explosion-proof fluorescent systems on a typical coal mine longwall face.