SAFETY IN MINES RESEARCH ADVISORY COMMITTEE

SIMRAC

Final Project Report

Title: A REVIEW OF THE ILLUMINATION PROBLEMS PERTAINING TO SOUTH AFRICAN COLLIERIES

Author/s: D R Pardoe and D V Molesworth

Research Agency: Miningtek

Project No: COL 033a

Date: January 1994

A REVIEW OF THE ILLUMINATION PROBLEMS PERTAINING TO SOUTH AFRICAN COLLIERIES

Final Report on SIMRAC Project COL 033A:

by D R PARDOE and D V MOLESWORTH

January 1994

CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

There is a need within the coal mining industry for improving safety, particularly with regard to the operation of mobile machinery, and the effectiveness of underground illumination is considered to be an important factor in this regard. The majority of coal mines transport men and materials using free steering vehicles. The visibility to machine operators of pedestrians and obstacles in travelling roads is therefore vital, as is the visibility of the moving machinery to pedestrians.

Sight is probably the most important, certainly the most extensively used of the human senses. Adequate illumination is, therefore, required to ensure safety and productivity. The coal face emerges as one of the most difficult environments to illuminate, due to the low reflectivity of the coal roof, walls and floor, the temporary nature of the working and travelling places, large distances, dust, and the need for flameproof equipment. Difficulties also arise because the headroom is restricted, thus limiting the mounting height of lighting fittings, and dusty atmospheres reduce the transmission of light from sources, while the normal surfaces in the mine have low reflection factors which lead to poor utilization of the light provided. It is a frequent comment by persons concerned professionally with lighting that their fellow engineers and managers give very little thought to it unless they are presented with specific problems. One explanation is that light from natural or artificial sources is so freely available that it is not considered necessary to design for the visul processes. However, the fact that miners are unable to work without the aid of artificial light has led to growing interest in designing systems to suit the mining environment.

The effectiveness of an illumination system in this environment is dependant upon technical features such as power, wavelength range, spacing between luminaires, etc., and practical features such as reliability, durability and ease of installation or relocation.

In 1992, a proposal was submitted to SIMRAC for a two year programme of work with the overall objectives of conducting a general review of problems and techniques related to underground colliery illumination, with particular emphasis on identifying means of enhancing safety in the vicinity of mobile equipment, and developing improved illumination techniques and procedures.

The original programme, which was to include tests on different types of illumination methods, and the development of specifications for improved illumination systems, was trimmed and restructured at the request of SIMRAC and limited to a one year "desk-top" study. On the assumption that the understanding of the requirements for the adaptation of illumination technology for underground colliery use was well advanced, it was still anticipated that the project would include some evaluations and field trials on alternatives to current illumination systems. It soon became apparent, however, that this was not the case and as the requirements of the investigation into the fundamental issues, the general complexity of the subject and the definition of the associated problems exceeded anticipated levels, it became necessary to focus the resources allocated to the project on those basic aspects rather than leave the studies incomplete, or incur delays and increased costs, in order to conduct tests on illumination hardware, which may not have been relevant or appropriate.

The primary output of this work is, therefore, a review of the current status of colliery illumination technology, equipment and procedures, the effectiveness of current applications of illumination systems and technology, particularly on mobile equipment in coal mines, and the identification and definition of problems that may be resolved through further research and development.

The work involved a review of general illumination theory, and the identification of the relevant criteria for effective underground illumination. Current applications and procedures were evaluated, problem areas identified, and mechanisms for improving systems or developing improved systems identified. These form the basis of the recommendations for further investigations and development work aimed at improving underground safety through the use of better illumination systems.

BACKGROUND

General Theory and Terminology

Light

Light is radiant energy of wavelengths in a small band of the electromagnetic radiation spectrum: approximately 0,4 to 0,7 microns. The radiant power of a light source may be measured by physical instruments which detect the "heating" effect when light falls on a surface. Such measurements are of the rate of energy received and are measured in watts. However, the radiation in this band is called light because, when it is received by the receptors in the retina of the eye, it creates visual sensation. Since the eye's receptors are not equally sensitive to radiation at all wavelengths within the light band, an alternative concept to radiant power is required to express its visual effect. The quantity is described as luminous power or more commonly as luminous flux and the unit of measurement as the lumen. The luminous power or flux (lumens) of a particular radiation can be calculated from its radiant power expressed in watts if the relationship between them for the given wavelength is known. The generally agreed relationship is: 1 watt equal to 680 lumens for radiation which has the maximum visual effect (at a wavelength of 0,554 μm, for photopic vision). At other wave lengths, a further multiplying factor having a value more than zero but less than 1, depending on the efficiency of the radiation at that wave length in causing visual effect, must be applied.

The radiation from most natural and artificial light sources contains emissions at more than one wavelength and thus measurements on the lines indicated would be very cumbersome.

Two alternatives exist: (a) to use an observer and thus the eye itself to make comparative judgements or (b) to employ physical instruments so designed that their sensitivity to radiation of differing wave lengths is the same as that of the human eye.

Quantities and Units

The system of quantities and units used in illumination engineering is based on the concept of luminous flux, measured in lumens (lm), as the rate of emission of light.

Illumination is defined as the density of luminous flux falling upon a surface, units being lumens/metre^2 (lux). The Luminous Intensity of a source is a measure of the concentration of luminous flux leaving the source in a given direction. Luminous intensity is a directional quantity being the solid angular luminous flux density in a specified direction. The unit used today is the candela (cd). The candela has replaced the older unit known as candle power (cp) as the unit of luminous intensity but, since a candle power and candela represent the same solid angular luminous flux density, confusion should not arise. One candela represents an intensity of 1 lm/unit solid angle. (A solid angle is the three dimensional space analogy of a plane angle measured in radians. The plane angle around a point is 2π radians, derived from dividing the circumference of any circle ($2\pi r$), drawn with the point as centre, by the radius of the circle. Similarly the solid angle around a point is 4π steradians, derived from dividing the area of any sphere ($4\pi r^2$), described with the point as centre by the square of the radius of the sphere).

Inverse square law

When dealing with sources, the dimensions of which are small compared with their distance from the point at which the resulting illumination is of interest, a simple relationship exists between the luminous intensity of the source in the direction of the point and the illumination produced at the point,

$$E = \frac{I \cos \theta}{D^2}$$

Where: E is the illumination produced at the point (lux),
I is the luminous intensity of the source in the direction of the point (cd),
D is the distance of the source from the point (m),
θ is the angle made by the ray from source to the point with the normal to the surface at the point.

This relationship is referred to as the Inverse square law combined with the cosine law.

Theoretically the relationship is only accurate for point sources. However, because of its simplicity it is often used to calculate the illumination resulting from real light fittings. It is therefore useful to estimate the degree of error involved when so doing. It can be shown that if the Inverse square law is applied to the calculation of illumination at a distance more than 4.5 times the largest dimension of the source the error is limited to 1%; at a distance more than 2.25 times the largest dimension; 5% and at a distance more than 1,6 times, 10%.

Luminance

When large area sources have to be dealt with it is necessary to define the light producing character of the surface of the source. Similarly it may be necessary to consider large surfaces which act as sources because they reflect light. For this purpose we refer to the luminance of the surface and use the unit candela per square metre (cd/m^2).

Vision[1][2]

Light receptors in the retina of the human eye consist of two types, rods and cones, which are not uniformly distributed over the retina. In particular the central portion, the fovea, which is used to see fine detail, contains a dense concentration of the fine cone receptors and no rod receptors.

There are three types of vision, depending on the luminance:

- Scotopic vision occurs at low levels of luminance, from 10^{-1} cd/m^2 to 10^{-2} cd/m^2. This involves primarily rod receptors and is characterised by no colour and better vision out of the corner of the eye than at the centre of visual attention.

- Mesopic vision occurs at luminances between 10^{-2} cd/m^2 and 10 cd/m^2, and is essentially a transition stage.

- Photopic vision occurs at luminances above 10 cd/m^2 and is characterised by full colour perception, as the cones are primarily responsible for vision, and by the ability to perceive fine detail. An upper limit of 10^6 cd/m^2 is defined as that at which physical damage to the retina occurs.

The eye can thus operate over a very wide range of luminance values - from 10^{-6} cd/m^2 to 10^6 cd/m^2. However, it can not operate efficiently if this complete range is visible at the same time, and the practical luminance range is about 10^4:1.

The time required to adapt to a lower luminance is greater than that for adaptation to a higher luminance, particularly if the former requires a transition from cone to rod vision. Complete dark adaptation from photopic vision can take as long as an hour.

The fovea is the region of the retina where the cones are located and most acute vision is obtained. If we wish to see an object clearly we look directly at it so that the image falls directly onto the fovea. The cones are not, however, as light sensitive as the rods, and at low levels of luminance colour vision is lost and peripheral vision becomes better than foveal vision. The eye therefore requires bright light for high resolution colour vision.

The rods and cones also differ in their ability to detect wavelengths within the visible spectrum. The retina responds to light with wavelengths between 400 and 700 nm in photopic vision and maximum efficiency arises with yellow-green light at about 550 nm. Scotopic vision gives a response to wavelengths between 380 and 660 nm with maximum efficiency at 510 nm and no ability to discern colours. These figures suggest that light with wavelenghts in the blue region would be most effective for scotopic vision, but where possible photopic vision should be available in which case green light would be the most effective.

The normal lateral field of vision is about 180° of which 120° is binocular. In the process of seeing, the eyes scan the subject and fixate momentarily at different points over it. The succession of images generated is integrated into a complete image by the brain. Only a field of about 2° is in sharp focus at any time.

Another noteworthy aspect pertaining to vision is the tendency of the eye to orientate towards and fixate upon more intense light sources. This leads to a distracting effect whereby direct light from miners cap lamps or vehicle headlamps can impede task performance by making it more difficult to fix attention on a darkened area.

Contrast[1]

Contrast is defined mathematically for achromatic tasks as:

$$C = \frac{L_o - L_b}{L_b}$$

Where: L_o = the luminance of the object
L_b = the luminance of the background

Contrast greatly influences our ability to see. No matter how brightly lit the visual task may be, if there is no contrast in either brightness or colour it is not possible to distinguish task features. Maximum contrast sensitivity is obtained with object luminance levels of between 380 and 470 cd/m^2 and background luminance levels of 32 to 95 cd/m^2. Higher luminance levels generally provide greater contrast sensitivity so that it will be easier to distinguish details on an object with a luminance value of 100 cd/m^2 against a background with a luminance value of 10 cd/m^2 than an object with a luminance value of 10 cd/m^2 against a background level of 1 cd/m^2 despite their both having contrast values of nine.

Speed of perception also increases with both the average level of luminance and the contrast value. This is another factor that is of importance in any analysis of the relationship between illumination and underground safety.

Vision Disorders[1]

Research has indicated that ageing has a significant effect upon vision. The eyes of young workers are generally more sensitive to light, have a greater range of adaptation, have a greater range of focus, and are more resistant to glare. Subjects in a 50 - 60 age group were found to require illuminance levels of 100 to 400 lux to match the performance of subjects in a 20 - 30 age group working with illuminance levels of 2 - 5 lux.

Nystagmus is a disorder that involves the inability of the eye to maintain fixation focus in certain circumstances. It is associated with particular forms of fatigue in conjunction with difficult conditions of visibility such as long periods of constrained viewing and poor illumination. A form of nystagmus, common to miners with more than 20 years of underground service, is referred to as miner's illness. It is characterised by excessive sensitivity to glare, impaired dark vision, headaches and dizziness, and is generally attributed to poor the illumination conditions prevalent prior to the introduction of electric cap lamps. Another form of nystagmus associated with underground operations is optokinetic nystagmus, known as conveyor belt sickness, where giddiness, loss of balance, nausea or mental confusion can arise from attempting to track the movement of objects such as coal on a conveyor belt.

Flickering of lights with a frequency of 5 to 25 Hz can cause problems such as headaches, fatigue and nausea in some people, and even lead to epileptic seizures in a very small number of cases.

Partial colour blindness affects approximately 10 % of men and can reduce the effectiveness of contrast due to some colours.

Local Regulations and Codes

In South Africa the provision of illumination is covered by Chapter 15 of the regulations, and the relevant sections outlining general requirements are 15.1, 15.2, and 15.3.

Regulation 15.1 basically states that if it is dark a light must be carried, while 15.2 requires various underground locations to be illuminated "adequately." There is no indication, in either case, of any requirement in terms of quantity or quality of light.

Regulation 15.3.1, which was amended in 1991, requires moving machinery to be illuminated so as to be "clearly visible." The only specific minimum standard stipulated in the Act appears in 15.3.2 and applies only to mobile machinery. This requires a minimum average light intensity of 10 lux at a distance of 20 metres from the machine, in the direction of travel. The basic objective of this stipulation is safety, in that the operator must be able to stop if he sees "dangerous conditions." This ability to stop must, obviously, be dependent on other factors such as the speed and braking capabilities of the vehicle, which are controlled, to some extent, by other regulations (eg: 18.4.2 etc.).

Prior to 1991, the regulation simply required the provision of an effective bright light shining in the direction of travel.

Regulation 18.4.2 indicates that the operation of any vehicle to be used for man transport is dependent upon the authorization of the Inspector of Machinery, and is therefore subject to any conditions that he may impose, such as maximum speeds etc. Whereas this regulation could be used to enforce compliance with illumination standards, no such standards appear to have been devised or implemented to date.

The Mines and Works Act also prescribes procedures for the reporting of accidents; lays down requirements for various travelling ways to be maintained in a safe condition; and requires permission or "approval" for the use of lamps underground. Once again, none of these gives any indication of standards for the quantity or quality of light produced.

The South African Bureau of Standards (SABS) has devised SABS Code 0114 in respect of interior lighting, which is relevant to "industrial" applications, but is not designed to cater for the completely different standards of acceptability which would apply in the underground colliery situation. The SABS Code of Practice 098 covers the lighting of streets and roadways and addresses the visibility requirements of vehicle drivers and pedestrians with respect to each other, their immediate environments, obstacles, etc. Standards also exist in respect of the design and construction of cap lamps (SABS Code 1438).

The relevant components of the regulations, together with all related SABS standards are summarized in the Mine Ventilation Practitioner's Data Book edited by Dr A M Patterson and published by the Mine Ventilation Society of South Africa in 1992[2]. These provide definitions of all terms, outline the basic theory of illumination, and present recommendations for minimum illuminance levels at a wide range of underground and surface locations, together with some maximum glare index values. Typical performance characteristics of different light sources and international recommendations are also presented.

Recommendations for luminance levels in various industrial and commercial applications are summarized in tables given in the MVS data book, reproduced here in Appendix 1. It will be noted that, with few exceptions, the recommendations refer to target luminance only. Some limits on glare are indicated elsewhere in the document, but background illumination is not referred to and the need to design for the elimination of veiling effects due to glare, or obscuring effects due to inconvenient shadows, is ignored. In most of the applications covered, background illumination can be assumed to be an ineviatable bi-product of the primary (target) illumination; however, this will often not be the case in the underground colliery environment, and this provides a clear confirmation of the dangers of basing the establishment of standards on a "translation" of generic recommendations applicable to significantly different environments.

RESULTS & FINDINGS

Literature

The most widely employed literature concerned with the principles of mine lighting is Trotter's "The Lighting of Underground Mines" (USA 1982)[1]. This book addresses all aspects of illumination in mines, from basic theory and operating mechanisms of the human eye, to practical aspects of underground illumination and the relationships between illumination, accidents and productivity. A key point that emerges from this book is that "seeing effectively" is more complex than merely being dependent on the amount of light being shone at a target. Two key variables are "contrast ratios" (targets to their background) and reflectivity of "targets".

Trotter also reviewed research into the correlations between illumination and accidents, and illumination and performance. Confirmation was provided regarding the lack of data to enable the precise influence of illumination on accidents and productivity to be defined; however evidence was presented that indicated some consistent degree of correlation between accidents, fatigue and illumination.

Other documents from the USA which provided useful information included:

- Underground Coal Mine Lighting Handbook (in two parts) which reviewed illumination theory and applications in USA collieries, and was published by the US Department of the Interior. This document incorporates a review of illumination theory and summarizes techniques by which the theory can be implemented effectively.
- Analysis of Work Areas and Tasks to Establish Illumination Needs in Underground Metal and Nonmetal Mines which detailed research into the different vision requirements of a wide range of underground tasks conducted by Perceptronics on behalf of the USBM.
- Human Factors in Mining (IR 4656): An annotated bibliography on various ergonomic and human task-related problems, including a section on illumination and visibility.
- Human Factors in Mining (IC 9182): detailing research into ergonomics and human task-related problems.

Australian research was summarized in a series of extracts published by W B Bell, and focused upon work carried out at the University of New South Wales which involved extensive evaluations of different luminaires used or intended for use in the underground environment.

Practices in the EEC were outlined in the Guidelines on the Ergonomics of Underground Illumination in Coal Mines as published by the Community Ergonomics Action group on behalf of the European Coal and Steel Community.

Details of illumination recommendations from the former Soviet Union were extracted from the COMECON Standards manual.

Information pertaining to standards and practices in South Africa was obtained from SABS codes of practice: 098 and 0114 covering Public and Interior lighting respectively; and the MVS data book which detailed guidelines for illumination in mines.

In general, overseas reports indicate that, while the principles of effective illumination are understood, the problems of practical application are universal. Attempting to satisfy the visual requirements of men using machine and hard-hat mounted incandescent spot lights is not an ideal solution in the underground environment. Such systems will always be a compromise since required light output inevitably results in problem of glare. Excessive glare is not and should not be tolerated since it represents discomfort (eye strain) and a safety hazard. Other practical constraints make the adoption of stationary lighting difficult.

Various reports, theses and papers were also reviewed, covering many developments in the fields of illumination, ergonomics and accidents.

A full bibliography is provided at the end of this report.

The Implications of Illumination Theory

Brightness and clarity of an image are subjective factors based upon a complex interaction between the operation of the observer's eye and the levels of luminance of the target and associated backgrounds. Appropriate illumination for different locations is usually defined according to similarly subjective criteria. A need for basic illumination is identified in terms of common sense and regulations: a cap lamp or vehicle headlamp is an obvious prerequisite for any activity, while additional lighting may be installed to provide perceived safety benefits or to enhance the environment and productivity. The types and locations of installations tend to be based upon other installations that are deemed to have been succesful in reducing hazards or enhancing comfort and productivity. With the passage of time, generic solutions to illumination problems have been established, and many authorities can now present list of recommendations in terms of the basic parameters that are easiest to define and measure. Table 1 below gives the recommended illuminance levels for various locations in South African mines as laid down in the MVS Data Book.

Although maximum glare values are indicated in some of the tables in Appendix 1, the figures presented take no cognisance of the complex nature of vision, and the need to consider the configuration of installations and any sheilding with respect to normal fields of vision or the creation of hazardous areas of shade.

The Machinery and Occupational Safety Act and the Mines and Works Act ignore glare and background illumination completely. The same applies to most overseas authorities, where increasing demands for total illuminance levels have, in many cases, led to increased hazards for underground workers.

The nature of tasks and targets in the underground workplace must also be considered. Analyses of tasks in the underground workplace[4] indicate that approximately 20 % of the tasks require near acuity and 30 % far acuity. 60 % of the tasks require depth perception, while 50 % require adjustment of focal distance. Nearly 20 % require some peripheral vision. Less than 5 % require colour discrimination.

These details then establish the basic criteria for good visibility, against which the normal illuminating mechanisms can be assessed.

Problems with the visibility of objects are generally associated with reflected light, ie secondary illumination, whilst glare, and the availability of light are due to the characteristics of the primary sources of illumination. It should, however, be noted that highly reflective surfaces can also transmit direct reflections of high intensity sources, for example: glass inspection covers can reflect images of cap lamps and vehicle headlamps - the intesity being dependent upon the angle of incidence. Obscuring effects such as the formation of shadows can also impede visibility, and need to be considered in any illumination system design.

Although the ideal mechanism for identifying objects is through revealing illumination; ie the target is illuminated more brightly than the local or general backgrounds, it is possible to distinguish the presence and movement of objects from their being silhouetted against an illuminated background; however, the lack of target detail limits the amount information the observer can derive from the scene.

	Suitable light sources			
	Incand-escent	Fluor-escent	Mercury Vapour	Sodium
Electrical and mechanical installations				
Sub-stations		X		
Switchgear rooms and sites		X		
Winder and hoist rooms		X	X	X
Winch chambers		X	X	
Fan chambers - permanent, in excess of 50 KW		X	X	X
Refrigeration plantrooms		X	X	X
Crushing and milling stations			X	X
Pump chambers		X	X	X
Battery charging bays		X		
Cement batching plant		X	X	X
Stores and storage areas				
	X	X		
Mining and engineering stores	X	X		
Fuel stores and refuelling bays	X	X		
Cable stores	X	X	X	
Cement stores	X	X	X	
Timber stores				X
First aid stations				
Development headings	X		X	X
	X			
On face - movable illuminations	X		X	X
Remote from face	X		X	X
Raise borer sites			X	X
Tunnel borer sites	X		X	X
Blind-hole borer sites	X	X		
Diamond drilling sites				
Waiting places				
	X	X		
Productions sites	X	X		
Stopes - on face, movable illumination				
Waiting places				

Table 1 : Types of Luminaire and Light Sources Recommended for Use in Mines

Contrast

Approximately 85 % of sensory information is derived from the eyes, making vision more important than all the other senses together. While there are means of measuring levels of illumination and associated factors, many of the aspects of vision are subjective and can only be evaluated through tests on subjects. Contrast is an example of an aspect that is evidently critical to vision, but which can only be assessed through modelling based on subjective input data. Three elements must be considered in the assessment of the effects of contrast: task illumination, local background illumination (with respect to the task), and general background illumination. International standards indicate an ideal ratio of 100:30:10 respectively. The task area is essentially defined by the area of foveal vision which is normally contained in a field of about 6 degrees. The zone surrounding this area must therefore be illuminated to provide 10^{-4} candelas/m^2 which is the threshold value for the rods of the eye, and will therefore ensure a response of the extra-foveal retina that will prevent the tunnel vision effect due to foveal vision alone. In terms of the above ratios, the minimum level for task illumination would therefore be 1^{-4} cd/m^2, however full task detail recognition is only acheived when the threshold level for the cone receptors is exceeded at a level of $10^{-1.5}$ cd/m^2, and acuity improves up to an optimum minimum level of 10 cd/m^2. This is a task illuminance level that can be attained using conventional cap lamps; however, the restricted beam of most of these devices (particularly those available in South Africa) is inadequate in terms of providing commensurate background lighting.

The underground working environment represents the minimum illumination scenario and presents severe constraints upon the acheivement of general background luminance levels. In view of this, the development of standards for underground illumination has tended to focus upon a simple target to background ratio and, given the requirement of 10cd/m^2 for target illumination, the absolute minimum acceptable background level has been established as 3 % of this.

The standards pertaining to contrast can, therefore, be summarised as follows:

- target luminance should exceed 10 cd/m
- background luminance should be between 3 and 30 % of the target value

Glare

Beyond the aspects of general visibility and contrast, consideration must be given to "veiling" luminance or the influence of relatively high luminance levels within the peripheral field of vision. Relatively high levels of direct light from luminaires typically deployed in the work place will impede and in some cases overwhelm the effects of low level background illumination. This phenomenon will apply in the case of cap lamps or vehicle headlamps operating in the absence of any significant background illumination, as will be the case at most operating faces. As a general rule, light from any source which exceeds 30 % of the target illumination must be considered detrimental to effective vision. The minimum luminance levels defined above must therefore be reconsidered in terms of any potential or likely veiling effects.

Glare is recognized as the discomfort due to direct light, whereas, in engineering terms, the effects are taken to be significantly more far-reaching; these represent any effect where peripheral illumination diminishes the effective vision due to the adaptation of the eye caused by the peripheral light altering the minimum target luminance and target/background luminance ratio requirements. Two categories of glare are therefore recognized: disability glare which leads to reduced visibility and visual performance, and discomfort glare which results in sensations of annoyance or pain.

The USBM has devised various methods for the mathematical definition of glare conditions:

The discomfort glare rating (DGR) for a single source is given as:

$DGR = M = L.Q/p.F_{0.32}$

where L is the source luminance (brightness) in the direction of the observer

$L = \pi ER^2/Ap$ (in footlamberts)

E = the illuminance at the observer's location
Ap = the projected area of glare source
R = the distance from the observer to the glare source (in feet)

Q is a function of the solid angle ω that subtends the glare source and extends to the observer and is defined empirically as:

$Q = 20{,}4\omega + 1{,}52\omega^{0{,}2} - 0{,}075$

and $\omega = Ap/R^2$

The DGR value for multiple glare sources is defined as:

$DGR = M^a_t$

where: the exponent $a = 1/n^{0.0914}$
n = the number of glare sources
$M_t = M_1 + M_2 + ... M_n$
$M_1 ... M_n$ = the indices of sensation of the individual glare sources.

These formulae may provide useful information in a laboratory setting, and may even give some indication of the glare that may be attributable to particular lighting sources, but their application in the dynamic environment of an active mining operation will probably yield less useable information than simple subjective evaluations of the circumstances pertaining to a particular problem.

Visibility vs Accidents and Productivity

Over 80 % of mine accidents are attributed to human error. Although many accidents are due to failure to observe correct procedures or negligence, many must arise due to ineffective training, lack of the proper tools/facilities, or a mismatching of human capabilities with the task to be performed, in the underground environment. The ineffectiveness of illumination systems, particularly in areas where mobile equipment is active in the presence of pedestrian workers, is unquestionably a contributing factor to the hazardous nature of this environment.

Although Trotter presented some data indicating a correlation between accidents and illumination, it is not possible, given the form and quality of data available, to prove any precise relationships between illumination, safety and productivity. Accident statistics and reports are not available in a form that enables the role of illumination to be isolated.

Figure 1 gives an indirect indication of the relationship between visibility and accidents through a comparison of accident levels in underground and surface operations for different age groups. The noticeable increase of accidents with age in underground operations is assumed to be related to deteriorating vision in an already poorly lit environment, as no such increase is apparent for surface workers.

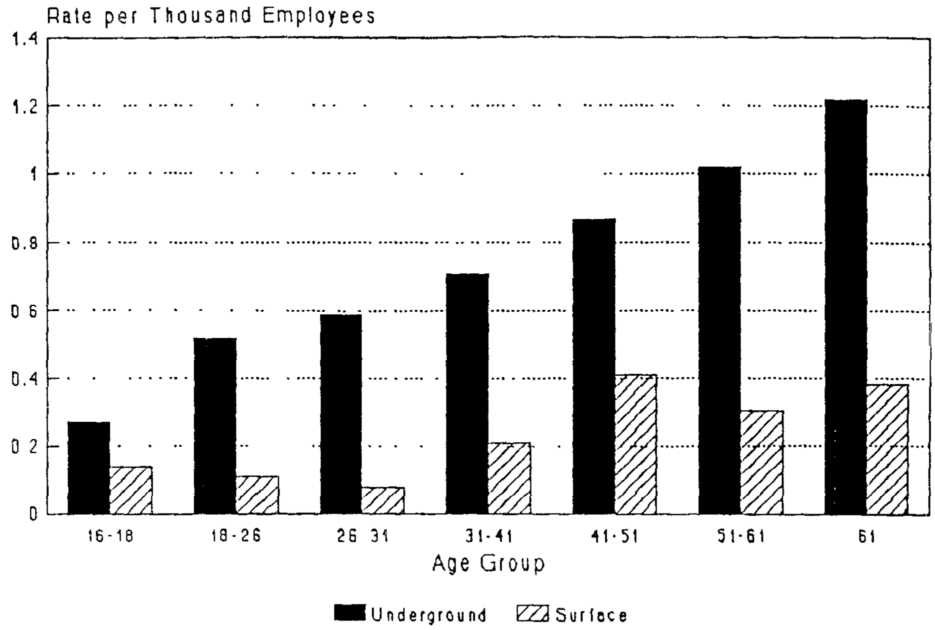

Figure 1: Fatality Rates in various Age Groups in British Coal Mines (1)

Figure 2 provides a more direct indication of the relationship between illumination and performance (as defined by the number of errors made).

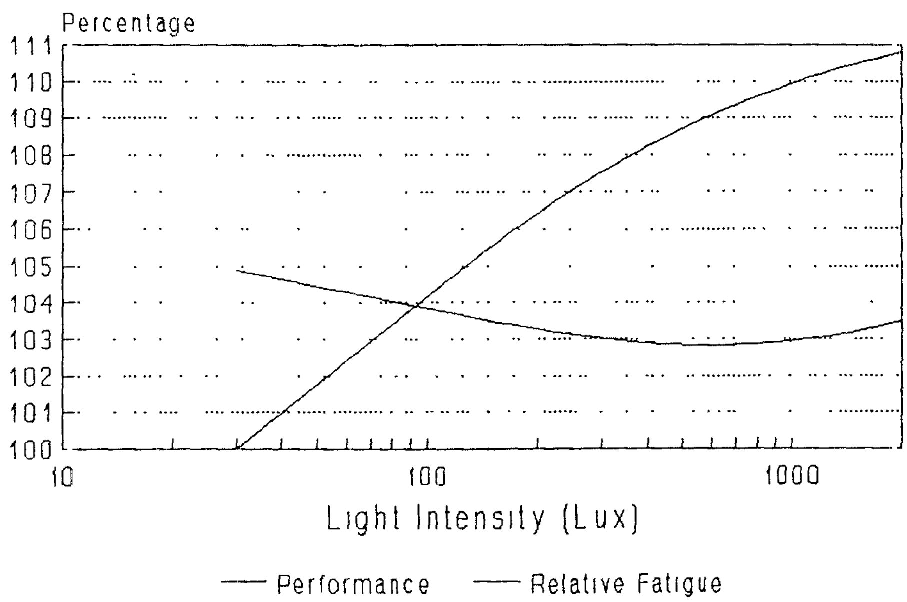

Figure 2: Effects of Light Intensity on Performance and Fatigue(1)

Whereas the existance of some relationship between illumination and accidents, and illumination and reduced productivity, can be presumed, neither accident nor performance analysis methods enable this relationship to be defined with any accuracy. For such techniques to be developed, however, the application of illumination in the underground work place has to become far better understood, and the science refined and implemented accordingly.

Illumination Practices

On the basis of the theory, diverse practical recommendations have been embodied in different international codes of practice. While based on the same accepted principles, there is significant variation in the strategies adopted to cater for the visual needs of workers.

The apparent motivation underlying the USBM studies of illumination has less to do with productivity and safety, than with improving the "quality of life of miners" in order to reduce absenteeism, staff turnover etc. Studies have been conducted into the effects of the quantities and type of illumination upon workers. The results indicate that any prolonged lack of exposure to various of the components of natural light can have a significant detrimental effect upon health. Inappropriate levels and types of illumination can produce stress, emotional conditions and fatigue that ultimately influence safety and productivity. These aspects were not considered to be within the scope of this study and detailed examinations of them were not carried out.

The regulations regarding illumination in the USA are probably the most comprehensive, representing the only attempt to address the need for background illumination in the vicinity of mobile machinery. Apart from target illumination regulations, there are federal specifications for luminance levels around most items of longwall and continuous miner face equipment. Lists are given, supported by schematics, outlining zones around these items of equipment that must be illuminated to give luminance values of 0,2 cd/m^2 (0,06 fL). For example, an area equal to the height and width of a shuttle car, 3,05 m (10 ft) to the front and rear of a shuttle car must have a luminance level of 0,2 cd/m^2. This value also applies to the entire face, ribs, roof, floor and exposed machine surfaces of a continuous miner up to the point at which the shuttle car or conveying equipment abuts against the machine.

The European guidelines focus entirely upon permanent and semi-permanent installations, and, once again, lighting requirements within the face areas are limited to very basic target illumination values. As with many national health and safety codes, developments within the mining industries of Europe have begun to move away from regulations and design specifications, towards guidelines and the requirement of codes of practice from mine managers that are established to ensure the safety of the workforce. In practice, this enables local authorities to redefine acceptability in terms of any particular aspect, as technological development facilitates improvements. It may therefore be that European authorities do or may soon require more comprehensive illumination strategies, but, for the present, no standard specifications can be defined beyond the basic requirements of law.

The standards laid down in the COMECON Standards manual require illuminance values of between 2 and 10 lux for key targets. For instance: vertical and horizontal surfaces of control panels and coal mining machines: 5 lux; floor illumination, horizontally along travelling ways: 2 lux; coal transfer points: 10 lux; illumination on floor behind heading machines: 2 lux. Reference is also made to contrast ratios for objects in the same plane.

Notwithstanding the Federal specifications of the USA, it is clear in any evaluation of rules and guidelines pertaining to the illumination of underground workplaces, that the emphasis is upon supplying some minimum quantity of light, without any consideration being given to the effeciency or effectiveness with which that light is utilized. Usually, the solution to illumination problems is taken to lie in an increase in the total illuminance around an object. The theory indicates that, without giving equal consideration to contrast, glare and other veiling or obscuring effects, increasing illuminance may not resolve a problem, and may in fact make it worse.

Rules and regulations can, therefore, be summarized as catering for minimum requirements only, ignoring, in most cases, the potentially overwhelming effects of glare and other obscuring features of illumination systems.

Practical Problems and Issues

In studying the application of illumination theory, the coal face emerges as one of the most difficult environments to illuminate, due to the low reflectivity of the coal roof, walls and floor, the temporary nature of the working and travelling places, dust, and the need for flameproof equipment. With a background illumination level that is zero, all incandescent lamps have the potential to cause glare. In this case, very dim but even illumination may be more effective than very bright headlights.

Bord and pillar operations, which represent the predominant primary and secondary development configurations, are characterised by rapid rates of geographical expansion: the duration of activity within one heading is a matter of hours, and production activities move between the seven to 15 production "zones" that will typically exist in a section. One of the principal problems pertaining to the illumination of the underground environment is, therefore, the need for the frequent expansion or relocation of the lighting system, and this is exacerbated by the need to provide flameproof enclosures and equipment.

As the bord and pillar coal mining process involves frequent and regular movements of vehicles in all the active work places, the installation and movement of lights and cables throughout all production zones within the section would involve disruption of operations and the need for additional manpower that would result in significantly higher and unsustainable production costs.

The provision of background lighting throughout the section must therefore be considered impractical in bord and pillar operations. General area illumination tends to be confined to the waiting place and, in some cases, semi-permanent installations such as switch-gear bays. The provision of general area lighting within the production zones can only be considered if it is directly associated with the operation of equipment, such that lighting is only provided as and when necessary; ie as and when production equipment enters one of these zones. Essentially, the lighting has to be mounted and operated onboard the machines.

Whilst capital and operating costs of lighting systems tend to be only a small component of overall costs, cost effectiveness is an aspect that is deemed important by many mine personnel:

- Tungsten filament and halogen lamps tend to be the least efficient in terms of converting energy to light, however they are relatively durable and easy to replace. They are generally used in applications that require intense target illumination, and involve movement, vibration or a high incidence of maintenance.
- Flourescent-tube lighting is more efficient in operation, but tends to involve a higher capital cost, is significantly more fragile and requires a more complex electrical infrastructure. Luminaires need to incorporate protection for the arc discharge tubes, and standard products tend to be large and relatively heavy.

In the case of luminaires based upon devices such as sodium lamps, consideration has to be given to the hazards that may arise through breakage, whereby liquid sodium could be released. This can present a hazard to workers, and will result in a violent reaction if contact with water takes place. The disposal of failed lamps presents a problem for the same reasons.

The source of electrical energy is also a factor that must be considered in the design of an underground lighting system. Limits on the range of suitable voltage levels or the availability of AC supplies, and the likelihood of significant fluctuations or cuts in the power supply, must all be accommodated in the design process.

Another practical aspect is the time taken for lights to become fully operational. Mercury vapour lamps offer long lives and good illumination capabilities, but will take from seven to nine minutes to "warm-up" fully. Mercury vapour and metal-halide lamps must also cool down before "re-striking" can take place and it may take up to 20 minutes for some of these lamps to resume full operation after any interruption in the power supply.

In all cases, the final choice of a light source has to accommodate consideration of the following:

- size, shape and weight of the luminare, including any sheilding necessary to eliminate glare or protect the lamp
- compatibility with the existing or envisaged infrastructure
- safety of operation, maintenance and (in some cases) disposal
- ease of operation (including installation and relocation where appropriate) and maintenance
- likely life span and reliability
- performance characteristics such as warm up times, or progressive deterioration of output with usage

Light Sources

A luminaire is defined as a complete lighting device including both lamps and parts to distribute light. In order to be viable in a colliery environment, such a device must be adequately robust, flameproof (or intrinsically safe), easy to install (and relocate where appropriate), as well as a suitable source of illumination.

Luminaires can be evaluated not only in terms of illuminating capabilities, but also in terms of initial and operating costs and efficiency.

As a source of light a luminaire can be assessed in terms of two basic aspects: the means of light generation; and light distribution, which in turn can be attributed to the use of reflectors and diffusers or other mechanisms.

There are two main mechanisms by which light is produced in manufactured sources:

- incandescence: produced by electrically activated tungsten filaments or quartz halogen elements.

- photoluminescence: produced by the electrical excitement of gases in arc discharge tubes, for example flourescent lamps, sodium lamps, mercury lamps.

Cap lamps and vehicle headlamps on highly mobile vehicles need to respond quickly to activation; be robust and capable of withstanding vibration and movement; and be easy and cheap to maintain or repair. In these situations, incandescent lamps offer the most practical solution. They are, however, characterised by being high intensity sources which produce glare.

Flourescent lights radiate light from much greater surface areas and therefore give good illumination over wide areas with less glare than incandescant sources. Shielding is still necessary in many locations however. These are suitable for general area illumination, but the fragility of the arc discharge tube and the need for complex electrical infrastructure necessitates the use of quite robust and substantial luminaires. The ease with which these lights can be installed and relocated is therefore limited, and their use is generally confined to waiting places, substations and other areas where their movement will be associated with the relocation of other heavy equipment.

Sodium lamps produce a monochromatic light which tends to provide clearer images in the eye, and penetrate mist and dust more readily, although the nature of the light does impair colour discrimination. Spot lights based on sodium lamps have been tried on continuous miners, but the benefits were often negligable and the high costs could not be justified. Other applications tend to be in more permanent installations where colour discrimination is not important.

Mercury vapour lamps tend to produce very high intensity light and as such are not suitable for the coal face. As with sodium lamps, their application is limited to permanent locations, but, in this case, good colour discrimination is catered for.

The MVS data book gives a listing of suitable light sources for different locations as presented in Table 1.

Other Sources of Luminance

Various characteristics of materials can contribute to enhanced visibility. The use of white in workers clothing is an obvious means of ensuring the maximum reflectance for the type of material used.

On a scale of 0 to 1, coal has a reflectance value of between 0,02 and 0,2, and shale values between 0,25 and 0,5. Depending upon its chemical composition, stonedust can have reflectance values of up to 0,75. The distribution of stonedust in production areas can, therefore, provide for the more efficient distribution of light in the section and increase background illumination levels. These benefits will, however, be confined to the areas that are available for stonedusting, which, in general, will exclude the active headings and splits.

Whitewash, which can have reflectance values in excess of 0,9, may provide more permanent benefits in workshops, shaft-bottom areas, main travelling ways, etc., but can obviously not replace the need for stonedusting.

Reflective tape, incorporating materials that return light to its source is another mechanism that is used to increase the visibility of pedestrian workers and obstacles along the line of cap-lamp or vehicle-headlamp illumination.

Flourescent materials appear unusually bright, particularly in the presence of ultraviolet light, and phosphorescent materials continue to glow for some time after being activated by an ultraviolet or radioactive energy source.

Illumination in the Vicinity of Mobile Equipment

Apart from the low reflectivity typical of a coal mining environment, most efforts aimed at illuminating the work place have focused upon small high-intensity light sources. While these are essential to ensure adequate illumination of tasks, the lack of contrast due to the absence of background illumination severely impedes visibility. These problems are at their worst in the case of illumination in the vicinity of mobile machinery; the distances and relative speeds characteristic of the operation of mobile equipment reduce the capabilities of both cap lamps and vehicle headlamps to small, high intensity sources of glare that provide virtually no background illumination and, therefore, no effective target illumination. In many cases these light sources afford no discernible target illumination either, and become nothing but sources of glare.

Some means needs to be established to improve the perceived luminance of targets for vehicle operators, and, if possible, the luminance of vehicles as perceived by pedestrian workers.

Retro-reflective tape offers one means of providing sources of higher intensity luminance in the fields of vision of both vehicle operators and pedestrian workers, who become illuminated by the vehicle headlights or cap lamps respectively. The identification of hazards will still tend to be by default: the reflective source can be identified as something bearing reflective tape, due to the shape, size and different level of luminance (relative to cap lamps or headlamps), and as such can be deduced to be a hazard. It will not, however, in many cases, be possible to identify the exact nature of the hazard.

The use of phosphorescent materials requires an energy source to activiate them, and as such will only be effective once the material has moved out of the range of some direct source of illumination. There is likely to be no benefit during the critical period in which the vehicle/light source and object/hazard are approaching, other than that due to the general high reflectivity of the materials.

The use of phosphorescent and flourescent materials could offer solutions if the amount of visible light were reduced to eliminate glare, and additional sources of ultraviolet light were introduced. This would amount to the introduction of a "black light" system where the high intensity sources would be invisible and therefore produce no veiling effects, but targets hazards and other objects would become sources of luminance. Unfortunately, ultra-violet light may introduce additional hazards that far outweigh the benefits of increased hazard visibility. It is known that ultraviolet light is responsible for tissue damage in the eyes and skin. Black light is considered by many to be a relatively weak source of "near" ultra-violet light (320 to 380 nm), threshold levels are significantly higher than the far and mid-range ultra-violet light normally associated with tissue damage. Studies on the effects of prolonged exposure to black light in discotheques and research laboratories give some indications that skin and eye tissues may be affected, and the safety of mine workers, who could be exposed to such light for much longer periods, is therefore questionable; such an application could not be considered without extensive further research.

As outlined above, background illumination effects are enhanced when the reflectivity of the walls and roof are increased through the application of stonedust. Apart from enabling improved visibility in conjunction with target illumination, silhouette effects in the absence of target illumination can be partially effective in facilitating the identification of hazards and movement.

It must be noted that visibility, whilst depending primarily upon illumination, is also dependent upon the accommodation of objects within the field of vision as delimited by obstacles within the range normally defined for the eye. Many vehicles and operational layouts introduce severe constraints upon the range of visibility which can contribute to the hazards due to pedestrian workers or other obstacles being obscured. Figure 3 illustrates the results of an investigation into the limits on visibility for LHD operators.

In the absence of any means of improving visibility through the implementation of more effective illumination systems, consideration may have to be given to alternative mechanisms to ensure the safety of pedestrian workers and machine operators. Sophisticated and expensive technological solutions will not be justifiable given the current pressures on finances and skills, and the likelihood of any such systems introducing more problems than they resolve. However, simple and cheap remedies may now be available. In particular, the application of radio frequency (RF) tagging has been extended to the undergound colliery environment and may offer the industry a means of preventing the movement of machinery in the presence of pedestrian workers. Discussions on this concept with industry personnel brought to light many concerns about the possible disruption of productivity through the implementation of this technique; however, most respondents acknowledged the tendency of workers to adapt quickly to problems of this type, and adopt practices that would ensure no such disruption. In the final analysis, it was felt that the problems associated with such a system were preferable to the consequences of accidents, and far better than other options such as route-scanning/obstacle detection, or the use of infra-red cctv monitors, etc.

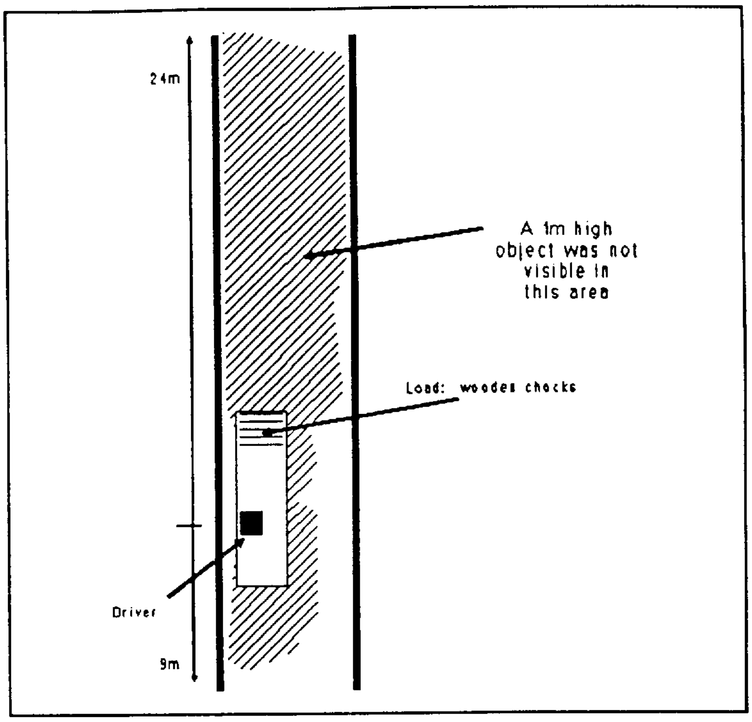

Figure 3: Limits on Driver Visibility from Laden Free-Steering Vehicle [5].

South African Collieries

Regulation 15.3.2 requires the provision of a minimum of 10 lux at 20 m in the direction of travel of any mobile machine. This is the only standard available to a local user/ designer of mobile equipment. The Mine Ventilation Society's Data Book contains no recommendations relevant to the coal face. No other local codes of practice exist. Equipment suppliers merely respond to the requirements of their colliery customers

Local research and development has been limited to attempting to define standards, rather than developing new technology. The National Committee of Mine Illumination made no recommendations regarding coal face illumination as a result of the difficulties in the task.

After the revision in 1991 of 15.3.2 in the Minerals Act, several collieries undertook tests of different headlamp/globe combinations. This resulted in a switch from wider beam-spread globes, to 14 degree beams and a doubling up of the single headlamp in some cases. As the largest supplier of face equipment, Joy Manufacturing commissioned similar tests in order to be able to advise their customers on how to comply with the new regulation and amend their own standards.

The same headlamp type and globe (in terms of wattage, 14 degree beam spread) are used on all machines (roof bolters, coal cutters, drill rigs, loaders, shuttle cars, continuous miners). The only difference is in the numbers used: one or two at each end (or more in the case of the continuous miner). The light output of a pair of such globes satisfies the requirements of Reg 15.3.2

In 1992 the Chief Regional Mining Engineer, E.Tvl Region, conducted a study into problems associated with Regulation 15.3.2. Recommendations have already been submitted to the GME regarding the amendment to the regulation. If implemented these will link the light output requirements to the stopping distance of individual pieces of mobile equipment.

A number of collieries have conducted independent trials concerned with aspects of the provision of lighting, such as the fitting of fluorescent luminares to mobile equipment to provide "general area lighting." However, there is little evidence that mobile equipment illumination is regarded as a general priority concern.

The status of illumination system development in South African collieries reflects the general lack of awareness of the extent to which poor visibility contributes to accidents; the limited understanding of the ineffectiveness of current illumination systems; and the concommitant failure to allocate resources to resolving problems within this area that is typical of mining industries around the world.

Current and Recent Research

The research conducted by or on behalf of the USBM has been the most far reaching encountered during this investigation. Task requirements, luminaire efficiency and effectiveness, and requirements in terms of contrast and glare avoidance have been examined in detail. New luminaires have been developed including very diffuse sources activated via broad fibre-optic lines. Regulations and guidelines have been amended to cater for background level requirements as far as possible. The emphasis of this work tends, however, to remain focused upon identifying solutions to generic problems rather than developing design techniques to ensure that illumination systems are tailormade for specific applications. Research has also been concerned with the practical designs of luminaires and the associated electrical/infrastructural equipment.

Computer programs for the design of mine lighting have been developed by companies in the USA (eg: Ocenco Incorporated), but the capabilities and effectiveness of these could not be determined during the course of this project.

The Human Factors Group is continuing with research into general visibility and ergonomics. Computer programmes and tools such as CAP (Crew-station Ananlysis Programme) and HERMI (Human Eye Reference Measurement Instrument) have been developed to enable the range of visibility from a vehicle operator's position to be defined, evaluated and, where appropriate, modified at the design stage.

The research programme carried out by the University of New South Wales has concentrated upon evaluation of luminaires from cap lamps to laser beams. The scope of these studies has been extensive, but has been almost exclusively concerned with the quantities of illumination produced by the different devices. Results to date confirm the problems that exist in the underground workplace: cap lamps and vehicle headlamps generally provide high intensity beams of light which are capable of illuminating target areas, but which do not provide peripheral illumination, and will cause glare in the absence of other background illumination.

The most important developments in Europe pertaining to this area have been in the field of equipment design and ergonomics. In some cases, illumination requirements have been established concommitantly, but little significant research has been conducted on the luminaires themselves or their general application in the workplace.

In South Africa, investigations have been carried out into several aspects related to illumination and visibility. In 1984 the Industrial Hygiene Branch of COMRO conducted a survey of illumination levels in gold mines based upon the figures contained in the annual ventialtion returns and confirmed the belief that illumination was often inadequate and an area requiring attention. The same division conducted a preliminary study into cap lamp design requirements in 1987 and confirmed the lack of information regarding requirements in terms of peripheral vision and background illumination.

Investigations into means of improving illumination have been carried out at several collieries during recent years, usually as collaborative efforts involving the mines, lighting system suppliers and the local Inspectorates. The Eastern Transvaal Regional Director provided details on tests carried out at Goedehoep, Greenside and ZAK collieries, in collaboration with Lascon Lighting. The outcome of these investigations was confirmation of the problems due to veiling luminance, particularly in cases where narrow beam luminaires had been adopted in order to comply with the revised legislation, and recommendations that the distance at which the minimum illuminance values (10 lux) are to apply should be linked to the speed of the vehicles. The studies at Goedehoep were more extensive, involving an evaluation of more practical aspects such as replacement costs and safety associated with different lamp types, and the use of flourescent luminaires on board coal mining machines.

SUMMARY OF FINDINGS

The safety of workers in areas where mobile equipment, particularly free steering vehicles, is used is a matter of growing concern, and accident statistics suggest that much remains to be done in this regard.

The problems of the safety of workers in the vicinity of mobile machinery is largely dependent upon the visibility of the pedestrian worker to the machine operator, and the visibility of the machine to the pedestrian worker. Visibility is not dependent upon illumination alone. The ergonomic design of the machine, to enable pedestrian workers, obstacles and any other hazards to be seen from the operating position aboard the machine, is every bit as important as the correct illumination of those items.

It is clear that illumination in any underground operation must satisfy three baisc requirements:
- target areas for both pedestrian workers and machine operators must be illuminated to higher levels than their local or general backgrounds
- background illumination of up to 30 % of the target luminance levels are required for ideal vision
- glare from small high intensity light sources must be avoided or accommodated through higher target and background levels.

The first of these requirements is the only one that is addressed universally in local collieries, through the requirements of the regulations for cap lamps and vehicle headlamps. Cap lamps and vehicle headlamps provide beams of relatively high intensity illumination. As glare from high intensity sources of light can in many cases completely obscure targets, underground workers exposed to glare, whilst in the vicinity of mobile machinery, are in as much danger as they would be if there were no illumination whatsoever.

The predominance of bord and pillar operations in South African collieries makes the installation of background lighting throughout active working areas impractical.

In view of these factors, it would appear necessary that solutions to the current shortcomings of illumination systems are devised with respect to the immediate vicinities of mobile machines; ie the machines themselves provide the infrastructure to enable the establishment of the illumination systems that are needed in their immediate vicinities.

Experiments have been conducted in the installation of shielded luminaires on board machines, with a view to creating improved background illumination levels and thereby counteracting the effects of glare. Unfortunately, the size of machines is usually such that mounting positions require shielding such that the deepest shadows occur in the most critical positions, and the full benefits of background lighting are not realised. Elevating the position of the luminaires sufficiently to overcome this introduces new difficulties in terms of height clearance and operating procedures. In many cases roadway heights make it impossible to install luminaires far enough above lines of sight to be effectively shielded, without severely limiting the extent of background illumination provided.

Research has been conducted into the use of light diffusion systems to spread light as far as possible from sources that can be shielded to prevent glare, but the problems of casting shadows across critical areas, and causing eye adaptation that reduces the effectiveness of cap lamp and headlamp illumination, persist.

The use of reflective materials has helped to increase target visibilities even in the presence of veiling illumination, but makes little difference to background luminance levels.

CONCLUSIONS

The issue of underground illumination in collieries has not been regarded as a matter of high priority despite apparent inadequacies and safety and productivity implications. Regulation 15.3.2 does not require or encourage a holistic/objective approach to illumination needs. The usual driving imperatives of safety, productivity and economy have not, generally, been translated into attempts to develop good lighting practice.

The underground workplace is difficult to illuminate

Results of the independent trials of fluorescent luminares on different machines deserve particular investigation and modification of the attributes of the headlamp output must be considered.

Cost effectiveness is not currently a constraint to the provision of more effective illumination. The challenges in attempting to improve the effectiveness of mobile equipment illumination are technical rather than economic.

Fundamental questions that must still be answered, and which require the consolidation of the work to date, include the following:

- whose safety is at stake?
- how should the visual needs of men be defined?
- is there a quantifiable relationship between illumination and safety hazards or productivity?
- what criteria should be used to define "effective" illumination?

There are many indications that illumination must be a key variable for safety, for instance, the need for a motorist to adjust his driving style during the transition from daytime to nighttime, or the distraction caused by having the interior light on during nighttime driving. Poor lighting represents an insidious hazard.

It is implicitly assumed or expected that the machine operator is able and willing to compensate for deficiencies in his visual environment. This assumption has not been tested. The effect of illumination on the behaviour and productivity of a driver is unknown. The evident exercising of caution forms the basis for a theory of the relationships between illumination, safety and productivity

The faculty of good vision tends to be taken for granted; there is little understanding what controls it and the involuntary nature of eye responses to lighting situations. Hence the visual environment of the coal face is rarely questioned.

The single biggest apparent problem identified to date arises from the need for the human operator to continually adapt to different levels of light when manoeuvring his machine. In complying with Regulation 15.3.2 the standard headlamp globe changed, in some cases, from a 27 degree wide beam to a 14 degree narrow beam, which worsened this problem.

The basis of Regulation 15.3.2 does not reflect the normal relationship between mobile machine operators and other men underground, with regard to responsibility for safety. This relationship is unavoidable given the need for frequent manoeuvring around right angle corners by mobile machines between working places. Clothing, hard hats and any equipment worn should have the maximum reflectivity to increase the visibility of the wearer.

There is currently no foundation upon which to base the establishment of appropriate mine standards and the responsible officials have no meaningful criteria through which they can ensure effective illumination.

There is a need to refine the science of underground illumination and to develop simple mathematical models that will enable the relative merits of different strategies for increasing the effectiveness of illumination to be determined. Codes of practice are required, but can only follow a thorough investigation and debate of fundamental issues. Attention has tended to be focused on the performance of luminaires and their abilities to meet the requirements of specific conditions. The design of lighting systems to meet all the demands of underground colliery operations requires a holistic approach and greater consideration of background illumination.

The use of materials with various reflective or flourescent properties may offer means of improving the visibility of objects along the line of sight as illuminated by cap lamps or vehicle headlamps. The use of black light could enhance visibility and reduce glare, but the detrimental effects of prolonged exposure to ultra-violet light remain questionable.

Visibility is not, however, dependent upon illumination alone. Research has been conducted into the ergonomic design of mobile equipment from the point of view of operator visibility, and many problems have been identified. Computer programs and other tools have been established to enable the design of equipment for far better operator visibility.

The infrastructure for the testing and evaluation of all aspects of illumination and visibility exists, and further developments in the fields of both illumination and ergonomics should be possible without the delays and expense normally incurred in the implementation of such research programmes.

RECOMMENDATIONS

Further research and development is required in the following areas:

- the establishment of holistic design requirements for underground illumination systems that will address both target and background lighting particularly in the vicinity of mobile equipment.
- research into the use of diffused light sources on mobile machines, and methods for shielding them against glare, needs to be extended
- holistic illumination design techniques need to be combined with vehicle ergonomic design methods to provide an integrated approach to resolving problems of visibility
- further development is required in the area of luminaire design to provide for light distributions that will be more effective in the underground workplace
- further research is needed into the effectiveness of different types of illuminating radiation, such as monochromatic light, black light, etc. The possible hazards associated with prolonged exposure to these types of radiation also require further investigation

REFERENCES

1 Trotter D A. The Lighting of Underground Mines. Montreal, Canada. January 1982.

2 Patterson Dr A M. The Mine Ventilation Practitioner's Data Book. The Mine Ventilation Society of South Africa. Johannesburg. October 1992

3 Bell W B. Mine Lighting Research Extracts. University of New South Wales. February 1986.

4 Perceptronics. Analysis of Work Areas and Tasks to Establish Illumination Needs in Underground Metal and Nonmetal Mines. Prepared for USBM. September 1980.

5 Langdon B. European Safety Year 1992. The Mining Engineer, March 1993.

BIBLIOGRAPHY

Aiken E G and Fowkes R S. Human Factors in Mining: An Annotated Bibliography. USBM Internal Report 4656. September 1987.

Bell W B. Mine Lighting Research Extracts. University of New South Wales. February 1986.

Cloete A, Bezuidenhout L and Allan D. Report on Lighting. Department of Mineral and Energy Affairs.

COMECON. Underground Illumination Standards. 1980.

Community Ergonomic Action. Guidelines on The Ergonomics of Underground Illumination in Coal Mines. European Coal and Steel Community. October 1987.

Department of Mineral and Energy Affairs. Mines and Works Act.

E & M J: Coal Equipment. New Lamp Technology Saves Time and Money. November 1992.

Engineering News Clues. Luminaire Range Ideal for Collieries. Engineering News. April 1993.

Erhardt L. The Contrast Dilemma. LD+A: Views on the Visual Environment. March 1991.

Erhardt L. (Untitled). LD+A: Views on the Visual Environment. February 1993.

European Economic Community. Officcial Journal of the European Communities; No L183. June 1989.

Government Gazette. Volume 308, No. 13002: Section 8 - Amendments to Chapter 15 of the Regulations. February 1991.

Illuminating Engineering Society of North America. Lighting Design and Application. February 1993.

Kosnik W D. Self-Reported Visual Problems of Older Drivers. Human Factors. 1990.

Langdon B. European Safety Year 1992. The Mining Engineer, March 1993.

Lewis W H. Underground Coal Mine Lighting Handbook (Parts 1 and 2). USBM Information Circular 9073. 1986.

Matelsky I. Encyclopaedia of Occupational Health and Safety, Volume 2, pages 1879 - 1881: Radiation, Ultraviolet, Visible and Infrared. 1983.

Osram (Pty) Ltd. Indoor and Outdoor Lighting. 1992

Patterson Dr A M. Mine Ventilation Practitioner'a Data Book. The Mine Ventilation Society of South Africa. Johannesburg. October 1992.

Perceptronics. Ananlysis of Work Areas and Tasks to Establish Illumination Needs in Underground Metal and Nonmetal Mines (volumes I and II). Final Report on USBM contract No J0387230. September 1980.

Reinhardt Dr M, et al. Entwicklung verbesserter Scheinwerfer an Grubenlokomotiven und Einschienenhängebahnen. Glückauf-Forschungshefte 53. 1992

Sanders M S and Peay J M. Human Factors in Mining. USBM Information Circular IC 9182: 1988.

Schröder H H E, Gardiner L R and van Rensburg A J. A Summary of Noise and Illumination Returns from Gold and Coal Mines for the Period October 1982 to September 1983. Chamber of Mines Research Report No. 3/85. September 1984.

South African Bureau of Standards. SABS 0114: Part I - 1973: Code of Practice for Interior Lighting, Part I: Artificial lighting. August 1973.

South African Bureau of Standards. SABS 1438: Parts I - V - 1987: Standard Specification for Helmet Light Assemblies for Miners. August 1987.

South African Bureau of Standards. SABS 098: Part 1 - 1976: Code of Practice for Public Lighting, Part 1: The lighting of streets and highways. November 1976.

South African Bureau of Standards. SABS 098: Part II - 1973: Code of Practice for Public Lighting, Part II: The lighting of certain specified areas of streets and highways. November 1973.

Trotter D A. The Lighting of Underground Mines. Montreal, Canada. January 1982.

Van Rensburg A J, Voss W W B and Kielblock A J. Visual Requirements for a Design Specification of a Miner's Helmet Light: a Preliminary Study. CHamber of Mines Research Report No. 17/87. March 1987.

World Mining Equipment. Mine Lighting: Stressful or Helpful. November 1985.

APPENDIX 1:

MVS DATA BOOK - RECOMMENDATIONS AND GUIDELINES

Light Source	Output Range (lm/lamp)	Control gear losses (%)	Rated life (h)	Lamp efficacy (lm/W)	Relative source size	Relative lamp cost	Colour rendering
GLS incandescent	200 - 27 500	Nil	1 000	8 - 18	Small	Low	Fairly good
Tungsten halogen incandescent	200 - 33 000	Nil	1 000 - 2000	15 - 22	Small	Medium	Good
Low voltage incandescent	100 - 800	Nil	350 - 1 000	15 - 18	Very small	Low	Fairly good
High efficacy flourescent	800 - 8 700	20	7 500	55 - 80	Large	Low	Fair
Improved colour flourescent	400 - 6 500	20	7 500	25 - 55	Large	Low	Good
Miniature flourescent	100 - 700	80	5 000	25 - 60	Large	Medium	Fair/Good
Colour corrected mercury	1 800 - 54 000	7 - 30	7 500	36 - 54	Medium	Medium	Fair
Tungsten-ballasted mercury	2 500 - 11 500	Nil	6 000	16 - 23	Medium	Medium	Fair
Metal halide	24 000 - 280 000	14 - 22	7 500	60 - 80	Small	Fairly high	Fair
Phosphor-coated metal halide	27 000 - 85 000	14	7 500	68 - 85	Medium	Fairly high	Good
Low pressure sodium	4 500 - 27 500	20 - 80	6 000	105 - 160	Large	Medium	Very poor
High pressure sodium	19 500 - 38 000	12 - 20	6 000	78 - 95	Medium	High	Fair

Table I: Industrial Lighting: Performance of a Variety of Light Sources

Table II: ILLUMINANCE IN MINES

Selection of International Recommendations for Illuminance Levels in Coal Mines

Country	Shaft bottom	Houses (engine, pumping etc)	Main roads (haulage)	Loading points	Under-ground offices	Loco-motive repair area/ inspec-tion area	Coal faces
Australia	20	20		20	100		
Belgium	20	25	10	20			
Canada	50	50	20	20	270	270	
Czecho-slovakia	15	20	5	20			5
East Germany	30	80	15	40			
West Germany	30	40	15	40			
Hungary	60	20	2	40		20	
Poland	50(s)	50(s)	2(s)	15(s)		50/100	
United Kingdom	70	30		30	60	50/150	
United States							15(s)

Blank space indicates that no official recommendation has been made.
Suffix s denotes statutory.

Table III: Recommended Illumination Levels for South African Gold Mines

Location	Recommended values: Min average illuminance (lux)	Max. glare value
Main travelling and access routes		
Ladderways in vertical shafts	20	-
Shaft conveyances for man riding	20	-
Inclined shafts or ramps with walkway	20	-
Shaft sub-banks	160	28
Banks of sub-shafts	160	-
Main access routes -		
shaft stations	100	-
haulages	20	-
access crosscuts	20	-
chair lifts - end points	50	-
elsewhere	20	-
ventilation doors	50	-
Ore transport and handling systems		
Conveyor beltways	10 - 20	-
Ore loading stations - boxes, bins, flasks, tips, grizzleys	160	28
Haulages - no walkways	10	-
Underground crushing and milling stations	160	-
Workshops		
Primary - major maintenance	400	25
Secondary - service only	160 - 400	28 - 25

Table IV: Illuminance Levels Prescribed by the MOS Act (Extracted from the Machinery and Occupational Safety Act of 1983)

Location/Industry	Illuminance (lux)
Ablutions	
Wash-rooms, toilets and changing rooms	100 (at floor level)
Abrasive blasting	
Sand or other	200
Assembly plants	
Rough work eg. frame assembly, heavy machinery assembly	100
Medium work eg. machined parts, engine assembly, vehicle body assembly	200
Fine work eg. radio and telephone equipment, typewriter and office machinery assembly	500
Very fine work eg. small precision assembly	1 000
Blacksmith	
General working areas	75
Tempering	50
Boiler house	
Coal and ash handling	75 (at floor level)
Boiler rooms	100
Building and construction	
Industrialised building plants	200
Concrete shops	150
General working areas	20
Walkways and access	5 (at floor level)
Cement, asbestos, gypsum, talc, etc, products and moulded goods	
Fiberising, mixing, shredding, flat and corrugated sheets and moulded goods manufacture	200
Pipe and pole manufacturing : mixing, spinning, reinforcing, stripping	150
Cement manufacture	
Control room, milling, conveying, drying, pumping, burners' platform, coal plant milling, feeding, bagging, bulk filling, loading	150
Vertical control panel face	200 (vertical illuminance)

Chemical works	
Hand furnaces, boiling tanks, stationary dryers, stationary or gravity crystallisers, mechanical crystallising, bleaching, extractors, percolators, nitrators, electrolyte cells	100
Controls, gauges, valves etc	100 (vertical illuminance)
Control rooms	
vertical control panels	200 (vertical illuminance)
control desks	200
General working areas	100
(See also OUTDOOR AREAS)	
Die-sinking and engraving	
General	200
Fine	500
Hand engraving	500
Electrical goods manufacture	
Impregnating processes, mica working	150
Coal and armature processes	
general	200
fine (eg instrument coils)	400
Electricity generating stations	
Turbine halls (operating floor)	200 (at floor level)
Blowers, auxiliary generators	100
Transformer chambers etc	75
Cable tunnels, covered ways, storage tanks	50
Battery and charging equipment rooms	100
Boiler front (operating floor)	150 (at floor level)
Between boilers (operating floor), stairs, galleries and operating platforms, and precipitating high voltage chamber	100 (at floor level)
Pulverisers, feeders, ash plant, conveyors (tunnel, junction tower)	75 (at floor level)
Boiler house and turbine house basements	100 (at floor level)
Pump houses and rooms, water treatment plant	100
Overland conveyor housing walkways	
Control rooms	50
vertical control panels	200 (vertical illuminance)
rear of control panels	100 (vertical illuminance)
control desks	200
Computer room	500
Switch houses and rooms	150
Relay and telecommunication rooms	200
Nuclear reactors and steam raising plant	150
Gas circulator bays	150
Reactor charge/discharge face	150 (at floor level)
High voltage substations	100 (vertical)
(See also OUTDOOR AREAS)	

Fire stations	
Applicance rooms	100
External apron	30
Forging	
General	100
Foundries	
Charging floor, tumbling, cleaning, shaking out, rough moulding and core making	100
Fine moulding and core making, inspection	200
Garages	
Parking areas (interior)	50
Washing, polishing, greasing	100
Service pits	100
Repairs	200
Work-bench	250
Apron fuel pumps	100
Gauge and tool rooms	
General	500
General factory areas	
Canteens/dining rooms	100 (at floor level)
Cloakrooms	100 (at floor level)
Entrances	100 (at floor level)
Rest rooms	100 (at floor level)
First-aid rooms	100 (at floor level)
Inspection area (Engineering)	
Rough work eg. counting, rough visual checking of stock parts etc	100
Medium work eg. go and no-go gauges	200
Sub-assemblies	200
Fine work eg. radio and telecommunication equipment, calibrated scales, precision mechanisms, instruments	500
Very fine work eg. gauging and inspection of small intricate parts	1 000
Minute work	1 500
Lifts	
Car interior	100
Motor room	300
Machine shops and fitters benches	
Rough bench and machinery work, rough checking and stock parts	100
Medium bench and machine work, ordinary automatic machines, rough grinding, medium buffing and polishing	200

Fine bench and machinery work, fine automatic machines, medium grinding, fine buffing and polishing	500
Extra-time bench and machine work, fine grinding	800
Materials handling	
Wrapping, packing, labelling and despatch	150
Sorting stock, classifying, loading	100
Offices	
Entrance halls and reception areas	100
Conference rooms, general offices, typing and filing	300
Computer and business machine operation	500
Drawing office	500
Outdoor areas	
Abattoirs	
lairage	20
race	50 (at floor level)
Ash handling, precipitator and fan areas	20 (at floor level)
Bulk loading, unloading areas where manual operations are performed	50
Bulk loading/unloading areas where operations are performed mechanically	10
Cool-water screens	20
Fuel-pumps	100
Storage areas (excluding dumps)	5 (at floor level)
Water clarification plant and storage tanks (operating areas)	50
Marshalling yards	10 (at floor level)
Main entrance and exits	20
Transformer and reactor terrain	20
High voltage yard, distribution and sub-station	10
Outdoor areas	
Gangways, catwalks, stairways etc	20 (at floor level)
Conveyor structure	10
Paint shops and spraying booths	
Rubbing, dipping, ordinary painting, spraying and finishing	200
Fine painting, spraying and finishing	300
Retouching and matching	500
Passages and lobbies	
All areas	75 (at floor level)
Photographic	
Safety light, darkroom	5
Refrigeration	
Chilling and cold rooms, ice making	100

Schools and educational institutions	
Stairs, corridors	100 (at floor level)
Class and lecture rooms	200
General working areas	100
Sheet metal	
Benchwork, pressing, punching, shearing, stamping, spinning, folding	150
Scribing	200
Sheet inspection	300
Shops, storerooms and warehouses	
Stairs, corridors	100 (at floor level)
General working areas	100
Stairs, escalators and ramps	
General	100 (at floor level)
Storage battery manufacture	
General	100
Structural steel fabrication	
General	100
Marking off	200
Telephone exchanges	
Manual exchange rooms (on desk)	100
Main distribution frame rooms in automatic exchanges	200
Battery rooms	100
Surgeries, hospitals and clinics	
Stairs, corridors	100 (at floor level)
General working areas	100
Theatres, cinemas and halls	
Stairs corridors,	100 (at floor level)
Booking offices	200
Projection rooms	150
Warehouses and bulk storing	
Small materials, racks, packing and despatch	150
Issue counters	200
Loading bays, large materials	75
Inactive storage	20
(Also see MATERIALS HANDLING)	
Welding and soldering	
Gas and arc welding, rough spot welding	150
Medium soldering, brazing and spot-welding eg. domestic hardware	200

Fine soldering and spot welding eg. instruments, radio set assembly	500
Very fine soldering and spot welding eg. electronic printed circuits	1 500
Woodworking and sawmilling	
Rough sawing and bench work, sizing, planing, rough sanding	150
Medium machine and bench work, glueing, veneering, cooperage	200
Fine bench and machine work, fine sanding	200

Table V: Recommendations of the SABS: Illuminance Minima and Glare Index Maxima: Industrial Buildings and Processes

Locations	Illuminance (min) (lux)	Glare index (max)
Ablutions		
Wash-rooms, toilets and changing rooms	160	-
Assembly plants		
Rough work eg. frame assembly, assembly of heavy machinery	160	28
Medium work eg. machined parts, engine assembly, vehicle body assembly	400	25
Fine work eg. radio and telephone equipment, typewriter and office machinery assembly	800	22
Very fine work eg. small precision assembly	1 600	19
Blacksmith		
General working areas	100	28
Boiler houses (industrial)		
Coal and ash handling	100	-
Boiler rooms	160	28
Car parks (indoor)		
Car parking :		
entrance	160	28
traffic lanes	50	-
Chemical		
Hand furnaces, boiling tanks, stationary driers, stationary or gravity crystallizers, mechanical driers, evaporators, filtration plants, mechanical crystallizing, bleaching, extractors, percolators, nitrators, electrolytic cells	160	28
Controls, gauges, valves etc	160	-
Control rooms : vertical control panel face (vertical illuminance)	200 - 400	19
Control desks	400	19
Electricity generating stations		
Turbine halls (operating floor)	320	25
Blowers, auxiliary generators	160	25
Cable, screens and transformer chambers	100	-
Cable tunnels, covered ways, storage tanks	50	-
Battery and charging equipment rooms	160	-

Boiler front (operating floor)	200	25
Between boilers (operating floor), stairs, gallereries and operating platforms, and precipitator high voltage chamber	160	-
Pulverisers, feeders, ash plant, conveyors (tunnel, junction tower)	100	-
Boiler house and turbine house basements	160	28
Pump houses and rooms, water treatment plant	160	22
Overland conveyor housing walkways	50	-
Control rooms		
vertical control panel face (vertical illuminance)	200-400	19
control desks	400	19
rear of control panels	160	19
Computer room	630	19
Switch houses and rooms	200	25
Relay and telecommunication rooms	400	22
Nuclear reactors and steam raising plant		
reactor areas	200	25
Gas circulator bays	200	25
reactor charge/discharge face	200	25
(See also OUTDOOR AREAS and OUTDOOR PLANTS)		
Explosives - see CHEMICAL		
Forging		
General	160	28
Foundries		
Charging floor, tumbling, cleaning, pouring, shaking out, rough moulding and core making	160	28
Fine moulding and core making, inspection	400	25
Garages		
Parking areas (interior), washing, polishing, greasing	160	-
Servicing pits	160	-
Repairs	320	25
Gauge and tool rooms		
General	800	19
General factory areas		
Canteens	160	-
Cloakrooms	160	-
Entrances	160	-
Inspection areas		
Rough work eg. counting, rough checking of stock parts etc.	160	28

Medium work eg: go and no guages	320	25
Sub-assemblies	400	25
Fine work eg: radio and telecommunication equipment, calibrated scales, precision mechanisms, instruments	800	22
Very fine work eg: gauging and inspection of small intricate parts, minute work	1600	19
Laboratories and test rooms		
General laboratories, balance rooms	400	19
Electrical and electronic instrument laboratories	500	19
Laundering and dry cleaning		
Receiving, sorting, washing, drying, ironing (calendering), dispatch	200	25
Dry-cleaning, bulk machine work	200	25
Fine hand ironing, pressing, inspection, mending, spotting	400	25
Lifts		
Car interior	160	-
Motor room	500	25
Machining and fitting		
Rough bench and machine work	160	28
Medium bench and machine work, ordinary automatic machines, rough grinding, medium buffing, and polishing	320	25
Fine bench and machine work, fine automatic machines, medium grinding, fine buffing and polishing	800	22
Materials handling shops		
Wrapping, packing and labelling	200	-
Sorting stock, classifying, loading	160	-
Mining (surface buildings)		
Preparation plants:		
working areas	100	-
picking belts	320	-
Winding houses	160	-
Lamp rooms	160	-
Weigh cabins	160	-
Fan houses	160	-
Outdoor Areas		
Bulk loading/unloading areas where manual operations are performed	50	-
Bulk loading/unloading areas which are entirely mechanical	10	-

Cooling water screens	20	-
Fuel pumps	160	22
Storage areas (excluding big dumps)	5	-
Water clarification plant and storage tanks (operating area)	50	-
Marshalling yards	10	-
Main entrance and exit	20	-
Transformer and reactor compounds	20	-
Roads, outdoor car parks Internal factory roads	In accordance with SABS 098-1967	In accordance with SABS 098-1967
High voltage yard, distribution and substation	10	-
Outdoor plants		
Gangways, catwalks, stairways etc	20	-
Conveyor structures	10	-
Paint shops and spraying booths		
Rubbing, dipping, ordinary painting, spraying and finishing	320	25
Fine painting, spraying and finishing	500	25
Retouching and matching	800	19
Passages and lobbies		
All areas	100	-
Refrigeration		
Chilling and cold rooms, ice-making	160	-
Sheet metal		
Benchwork, pressing, punching, shearing, stamping, spinning and folding	200	25
Scribing	400	25
Sheet inspection	500	25
Stairs, escalators and ramps		
General	160	-
Structural steel fabrication		
General	160	28
Marking off	320	28
Warehousing and bulk storing		
Small material, racks, packing and dispatch	200	25
Issue counters	400	19
Loading bays, large material	100	28
Inactive storage	20	-

Welding and soldering		
Gas and arc welding	200	28
Medium soldering, brazing and spot welding, eg domestic hardware	320	25
Fine soldering and spot welding eg instruments, radio set assembly	800	22
Very fine soldering and spot welding eg printed circuits	1600	19
Woodworking and sawmilling		
Rough sawing and bench work, sizing, planing, rough sanding	200	25
Medium machine and bench work, glueing, veneering, cooperage	320	25
Fine bench and machine work, fine sanding and finishing	400	25

Table VI: Recommendations of the SABS: Illuminance Minima and Glare Index Maxima: Public Buildings, Offices and Educational Institutions

Locations	Illuminance level (min) (lux)	Glare index (max)
Assembly and concert halls		
Foyers	50	-
Auditoria	50	-
Platforms	160	-
Stairs and corridors	160	-
Booking offices	320	25
Cinemas		
Projection rooms	200	-
Corridors, stairs	160	-
Foyers	50	-
Auditoria	50	-
Booking offices	320	25
Libraries		
Shelves (stacks)	50 - 160	-
Carrels, reading rooms (newspapers and magazines), reading tables	500	19
Binding	500	22
Cataloguing, sorting, stock rooms	320	22
Multi-purpose recreation halls		
General	200 - 630	-
Badminton	200	-
Table tennis		
club	400	-
championship	630	-
spectators	100	-
Gymnasia	400	-
Boxing		
amateur	1600	-
professional	2500	-
Offices		
Entrance halls and reception areas	160	-
Conference rooms, general offices, typing and filing	500	19
Computer and business machine operation	630	19
Drawing offices	800	16
Theatres		
Foyers	50	-
Auditoria	50	-
Corridors, stairs	160	-

Hospitals and clinics		
Reception and waiting rooms	160	19
Wards		
general	100	13
beds	160	19
Operating theatres		
general	400	10
Laboratories	400	19
Radiology	400	19
Casualty and outpatient departments	160	19
Stairs, corridors		
(in patient areas)	160	-
at night time	5	-
Dispensaries	320	19
Other rooms		
with specific visual tasks	400	19
Without specific visual tasks	160	19
Surgeries		
Waiting rooms	160	19
Consulting rooms	160	19
General	400	-
Laboratories	400	19
Corridors and stairs	160	-
Sight testing (acuity):		
wall charts and near vision tasks	300	-
Homes		
Kitchens	200	25
Bathrooms	100	-
Stairs	100	-
Workshops	400	-
Garages	100	-
Sewing, darning	630	-
Study and reading	500	-
Other rooms	160	-
Hotels and restaurants		
Entrance halls	160	-
Reception and accounts	320	-
Lounges	160	-
Bedrooms		
general	100	-
dressing tables, bed heads etc	200	-
Writing rooms (tables)	200	-
Corridors	50	-
Stairs	160	-
Billiard rooms:		
general	50	-

Card rooms	200	-
Launderies	200	25
Kitchens	200	25
Goods and passenger lifts	80	-
Cloakrooms and toilets	100	-
Bathrooms	100	-
Self-service counters	320	-
Shops and stores		
General areas	160	22
Stockrooms	160	-

ADDENDUM TO FINAL REPORT
ON
SIMRAC PROJECT COL 033A:

EXAMINE MEANS FOR IMPROVED ILLUMINATION IN COLLIERIES AS A CONTRIBUTION TO OPERATIONAL SAFETY

Following the review of the final report on project COL 033A, the EHAG subcommittee requested some elaboration on the specific problems pertaining to South African collieries, and on recommendations for further research. This addendum is presented accordingly, with specific problems listed in conjunction with outlines of how Miningtek would address research and development needs for the different aspects.

i) <u>The Establishment of Improved Standards for the Illumination of Colliery Workings</u>

Whilst this matter has been addressed with only limited success in recent years, further research and development can only proceed on an ad hoc and uncoordinated basis without the development of realistic targets for appropriate and acceptable luminance and illuminance levels, and definitions of suitable illumination characteristics.

The research to date has provided the necessary background material to enable the basic requirements of illumination systems to be identified. It should now be possible to enable the importance and interactions of these characteristics to be evaluated in the workplace, and the qualities of idealised illumination systems to be established accordingly. Realistic standards representing a substantial move towards ideal illumination could then be adopted as targets for further research and development.

Miningtek would envisage a research initiative capable of meeting these requirements proceeding as follows:

> An underground test site would be established in an area where exemption from fiery mine requirements could be secured to enable studies to be carried out on on a broader range of illumination systems than can currently be adapted to comply with flameproof or intrinsic safety requirements.
>
> The site would be equipped with mobile machines capable of imitating the actions of equipment typically used in colliery operations.
>
> A test protocol would be devised to enable the effectiveness of illumination systems in providing for the visibility needs of both machine operators and pedestrian workers engaged in production activities to be evaluated. The variables to be addressed in these trials would be contrast ratios; glare; light wavelength; and light band-width. The objectives of the tests would be to identify ideal and acceptable values for these parameters.

ii) <u>Enhanced Background Illumination</u>

Background illumination is crucial in providing for contrast and counteracting the severity of glare that are both necessary for good acuity of vision. The main body of the report outlined local difficulties in terms of the lack of understanding of the problems due to inadequate background illumination; the difficulties encountered in trying to provide background illumination; and the limited success of experiments in this area. It is likely that an increased awareness of the importance of background illumination would lend impetus to a more concerted research and development effort in this area, and it is clear that progress in this regard will contribute significantly to the provision of good illumination.

The developmental requirements with respect to background illumination lie in the areas of:

- the design of mineworthy diffuse/low-intensity light sources, capable of radiating light with characteristics that provide effective illumination with the minimum amount of glare.

- the development of means of shielding light sources to provide illumination through reflection, where resultant luminance levels preclude severe glare, and where control of scatter of light and planned entrainment of light, will facilitate the easier identification of hazards.

Research aimed at meeting these requirements would therefore address the issues as follows:

The basic requirements for lighting systems would be defined from i) above. Research prototype devices would then be designed and manufactured accordingly, to allow the practical constraints of implementing ideal systems, the various contributory factors to be determined, and short and long term developmental strategies to be established.

The test site established under i) above would be used for these investigations, and the different components of the theory, and the prototype devices would be tested under the most realistic operating conditions attainable given the need to control the various parameters and the other limitations due to the research process.

The main objectives of this programme would be to identify the best balance of source characteristics, shielding against glare, and the practical requirements for lighting systems.

Provisional specifications for luminaires and lighting equipment would then be discussed with manufacturers and industry personnel.

iii) <u>Machine Designs vs. Visibility.</u>

Attention was drawn, in the main body of the report, to the importance of recognizing the ergonomic shortcomings of many vehicle designs with respect to visibility, over and above the difficulties due to poor or ineffective illumination. Good visibility requires both effective illumination and freedom from obstructions in the field of view around machinery, particularly in the direction of movement.

Several computer programs now exist to support the design of equipment for good visibility with respect to both ergonomics/field of vision and illumination.

Development in this field would best be served through the acquisition of such a simulation facility and the testing of current and proposed [on the basis of ii) above] equipment designs and illumination system configurations. This work could also be usefully complemented through an analysis of operational practices which could be modified to minimize hazards and/or optimize the benefits due to improved illumination systems. Miningtek has already developed colliery production simulation tools that would enable the determination of the implications of any such modifications for productivity.

iv) <u>Improved Visibility Through Increased Relative Reflectivity</u>

Various techniques are available for increasing the reflectivity and visibility of different surfaces and thereby making the identification of hazards easier. The potential effectiveness of these will, however, only be realised when they are used in conjunction with improved general lighting that provides for the basic requirements in terms of contrast and glare.

Once means of catering for these basic requirements have been established, the evaluation of surface colours, reflective materials, fluorescent materials, etc. as means of enhancing visibility could easily be carried out as an extension of the aforementioned field trials.