illumination
in mines

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Introduction

Illumination is an important aspect of the mine environment. Underground mines are totally dependent on artificial light, as are surface mines in non-daylight hours. Mine buildings rely predominantly on artificial light.

Lighting in underground operations does not compare favourably with that in other industries with similar types of work. This can be attributed to a range of factors, many of which are unique to this environment e.g. diversity and mobility of workplaces, blasting practices etc. In surface operations, the sheer size of the workplace, in both vertical and horizontal dimensions makes provision of high quality lighting both technically and economically difficult. In both cases the poor natural reflectance of rock surfaces lowers the efficiency of any available light.

Because humans receive most of their information visually, the quantity and quality of lighting is critical to the safe and efficient performance of work.

Units and Terminology

Flux	- luminous flux is a power quantity which measures the flow of light energy per unit of time - it is measured in lumens.
Illuminance	- this is a measure of the density of light falling on a surface - it is measured in lux (lumens/m²) - it obeys the inverse square law.
Luminous Intensity	- this is a measure of the brightness of a point source - it is measured in candela (lumens/steradian).
Luminance	- this is a measure of the brightness of a distributed source - it is measured in candela/m².
Reflectance	- this is the ratio of reflected luminous flux to the total incident luminous flux - it is quoted as a percentage and varies widely with rock types.
Contrast	- this quantifies the difference in luminance between an object and its background

= (object luminance - background luminance) x 100 %
background luminance

	-colour contrast can also aid visibility, even when luminous contrast is zero, e.g. yellow object on black background.
Glare	- disability glare interferes with visibility and reduces visual performance - it is quoted as a disability glare factor (DGF) which indicates the percentage of visibility left, given the effect of the glare - discomfort glare increases eye fatigue and pain and causes distraction - tolerance of and sensitivity to discomfort glare varies from individual to individual the absolute intensity of a glare source is not important, but rather the difference in contrast between the source and the general adaption level of the eye.

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Relevance to Health and Safety

At the turn of the century, coal miners commonly suffered from an eye disease called nystagmus, which involved uncontrollable oscillations of the eyeballs, headaches and dizziness. It was thought to be caused by working for long periods under very low levels of light. It virtually disappeared with the advent of the electric caplamp. Several European studies have indicated that accident rates can decrease by as much as 60% when the overall level of illumination was increased. However, a recent Canadian study found that lighting was mentioned as a contributing factor in only 2% of accidents. The same study also found that in 13 separate underground fatalities between 1976 and 1985, coroners' juries have made specific recommendations with respect to lighting and some urged that research into mine lighting be conducted. Following the introduction of fluorescent lighting on a coal face in the USSR, productivity increased by 3.5% and the accident rate fell by 40%. In the Hungarian experiment, the accident rate in part of a mine illuminated by special purpose fixed lighting was 60% lower than in other parts of the mine where only cap lamps were used.

Prolonged lack of exposure to sunlight or to full-spectrum artificial light can cause various health problems including Vitamin D deficiency (causing brittle bones), behaviour deterioration, hypotania, hypoglycaemia, sinking of the basal metabolic rate, decrease in potency and libido, loss of hair, increased dental caries, insomnia, feelings of oppression, depression and irritability. Reduced absorption of ultraviolet light can also be due to the effects of certain types of glass including eye glasses.

Lighting that is adequate for visual needs is not necessarily adequate to prevent these health problems. Lighting that duplicates the natural light spectrum is best. A variety of studies have found that the use of full spectrum fluorescent lighting has produced a range of healthful effects.

Mine Lighting Related Problems and Possible Solutions

Problems	Possible Health Effects	Possible Solution
Excessive Glare	Stress, irritability, decrease in attention span	Maximum light source brightness of 3,000 cd/m² fixtures located above visual line; uniformity of lighting
Very Low Levels of Lighting	Nystagmus (inability to look at an object); constant eye movement; nausea	Use of Artificial Light ie. caplamps
Use of mercury vapour, sodium vapour, multivapour fluorescent	Deficiency of Vitamin D and poor absorption of calcium, sinking of basal metabolism rate, hypotania, insomnia, irritability, etc.	Use of full spectrum fluorescent lighting
Use of high sodium (pink to orange range) fluorescent lighting	As above, with increased irritability, decreased attention span over a period of hours	Use of full spectrum fluorescent lighting
Full spectrum or natural light blockage by equipment, windscreens, eyeglasses	Deficiency of Vitamin D and poor absorption of calcium, sinking of basal metabolism rate, hypotania, insomnia, irritability, etc.	Use of glass or plastic that allows UV transmittal

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History of Mine Lighting

Man's earliest mining activities were restricted to the earth's surface since the sun was the only source of light. The discovery of fire and consequently artificial light enabled mineral extraction to proceed underground. Archaeological discoveries have found evidence of mining activity considerable distances from the surface.

The earliest forms of lighting included wood chips, reed torches; strips of wood soaked in animal fat, rushes soaked in fish oil and oil poured into hollows in the rock. These were gradually replaced by the oil lamp, candle, kerosene lamp, carbide lamp and eventually electricity. Because of the often disastrous explosions caused by open flames m coal mines, there were many elaborate attempts at producing a light source without an open flame. These included using jars of fireflies, phosphorescent glow from decaying herring skins or moss, reflecting sunlight by mirrors, and Spedding's steel mill.

Although none of these was satisfactory, the absence of a suitable alternative saw steel mills used until 1812 when they were identified as the cause of a major explosion at Wallsend in North England. The public outcry caused a spurt in scientific activity to develop a truly safe light source.

A variety of "safety lamps" were developed in England and on the continent. In 1884 a Royal Commission was appointed by the British government to investigate mining accidents and test safety lamps. Over 250 different lamps were submitted for testing from the United Kingdom, Belgium, France and Germany. Although none of them was completely safe, four were selected as being better than the others. Their major problem was the use of a heavy oil as the fuel which required ignition by an open flame.

The first truly "safe" lamp was developed by Wolf in 1883 using naphtha type gasoline as the fuel. This allowed the lamp to be relit in the workplace using a built in lighter. The modem safety lamp differs only slightly from its predecessors and incorporates the key features discovered by tile early designers, i.e.

- fine wire screens to dissipate heat and confine the flame
- a bonnet to protect the discharge area
- a glass cylinder to enclose the flame
- naphtha fuel

Although calcium carbide was first obtained in 1862, it was not until 1896 that carbide lamps became economic. The addition of water to calcium carbide produces acetylene gas which bums steadily with a clean bright flame. A carbide lamp provides about ten times the light of an oil lamp of similar size. In coal mines, carbide lamps used the same construction as safety lamps to prevent explosions. They were replaced in gassy mines by electric lamps by 1920,but continued to be used in metal mines as they were useful for lighting fuses, served as an indicator of oxygen content, and provided a brighter light than, the battery powered lamps of that time.

The Electric Lamp

By far the single most important source of light in underground mines is the miner's cap lamp. The use of hand held lamps as a light source has now been superseded by the cap mounted lamp. These lamps are powered by either a lead-acid or a nickel-cadmium battery which weighs about 2.5 kg and is usually worn on the belt. The lamps are designed to give about ten hours before needing recharging.

There are three types of light source:

- tungsten filament
- fluorescent
- tungsten halogen

The tungsten filament lamp has been in use for more than 70 years and is the most common. In more recent times, fluorescent and tungsten halogen lamps have been developed but are still relatively rare. The fluorescent lamp does not provide a concentrated beam and is only suitable for tasks requiring a wide even source. The halogen lamp provides double the light of a filament lamp, lasts 50% longer, weighs less and provides more peripheral vision. It is likely that we will see more of these in the future.

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Lighting Systems for Mines

No operating mine can afford the luxury of a specialist lighting engineer, so solution of lighting problems, (if they are even recognised), is usually left to the electrical engineer, mining engineer, ventilation engineer or safety officer. Rarely are specialist consultants considered necessary.

Improved lighting requires more than an increase in light levels, it is also a matter of proper distribution of light. Light should come in the right quantity from the right direction, and should not introduce distractions or glare reflections to the work area. Although it is not feasible to light an entire mine, surface or underground, to the same standard for offices or factories, it is still possible to provide good quality lighting at important sites.

A variety of light sources are available and much better results can be obtained if the type and position of the luminaries are properly selected. A comparison of the various light sources suitable for mines is shown inTable 1.

In underground coal mines, light fixtures and their connections must satisfy the requirements for intrinsic safety. Lights can be fixed installations, portable, attached to machines or carried by personnel. They can be powered by electricity, compressed air or in some locations by wind or solar power. Proper maintenance is essential or the effectiveness of even the best system will rapidly deteriorate. Lights should be cleaned regularly, defective units replaced promptly and light levels measured to ensure continued effectiveness. Rock surfaces should be cleaned, and where possible whitewashed to improve reflectance.

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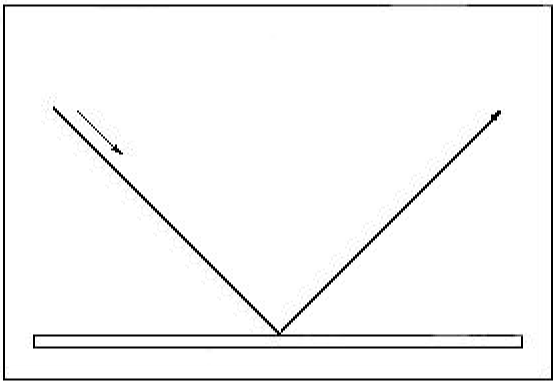
Lighting Standards

Detailed standards exist for levels of illumination in most existing industrial situations eg AS 1680 Australian Standard for Interior Lighting. However no such standards exist for mining operations, surface or underground. Mines regulations rarely deal with this area, and when they do it is usually very generally because of the difficulty of providing specifications for such a wide range of workplaces. Guidelines for mine lighting standards have been suggested for underground coal mines by Technical Committee 4.10 of the International Commission on Lighting (CIE). The mine lighting standards of some countries are specified in the following table from Vutukuri and Lama. (Table 2)

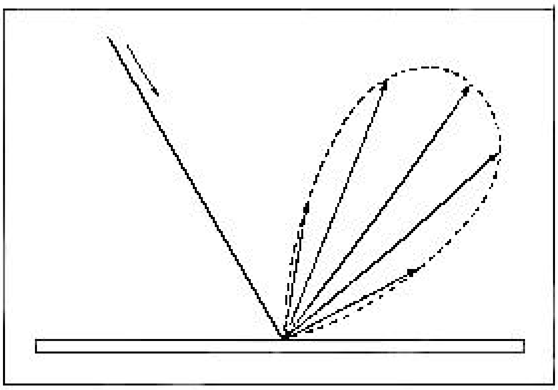
Measurement

Luminance and illuminance are measured by a photometer, using either a selenium photovoltaic cell or silicon photodiodes. It is important that the light sensor has a spectral sensitivity curve similar to that of the human eye. The ultimate test of any light source or lighting system is the human reaction to it, and some researchers believe that contrast sensitivity is a better index of visibility than photometer readings. Knowledge of reflectance of the surface is an essential part of light measurement and design. Light falling on a surface may be specularly reflected, diffusely reflected or both

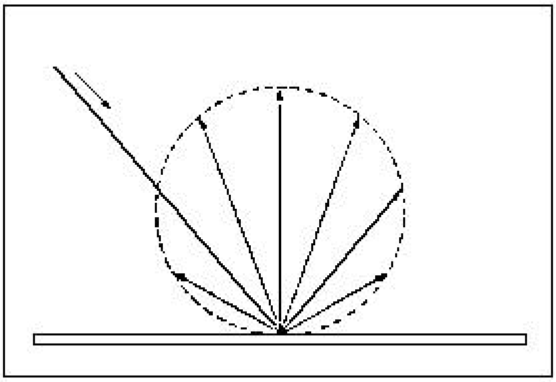
Types of Reflectance



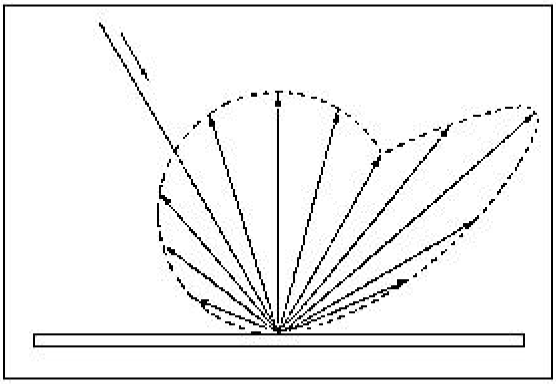
SPECULAR REFLECTANCE



SPECULAR DIFFUSE REFLECTANCE



DIFFUSE REFLECTANCE



DIFFUSE SPECULAR RELECTANCE

There are four techniques for reflectance measurements:

- reflected-incident light comparison.
- standard chips comparison
- reflectance standard comparison
- sphere reflectometry

The first technique is the easiest but the least accurate. The second is approximate but is usually adequate for design purposes. The third method is tedious but more accurate. The fourth method is the most accurate but requires special equipment.

Reflectance values range from almost zero for coal up to more than 0.9 for magnesite and white washed surface, so it is essential to have some idea of the value for the surface(s) that it is intended to illuminate. Experimental values for typical surfaces are shown in Figure 1.

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Experimental Results Of Reflectance Values

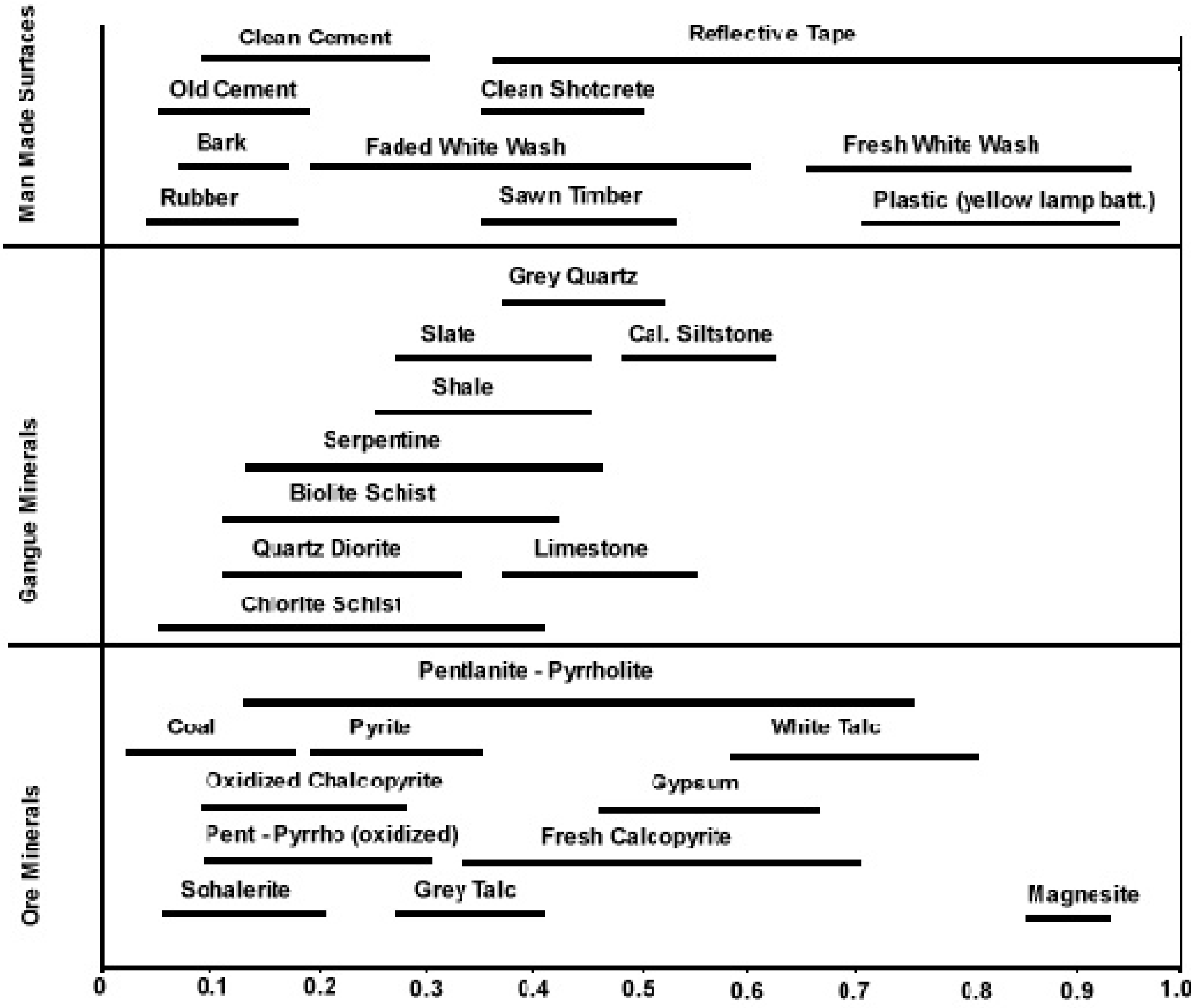

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Table 1 Comparison of light sources in mines (after Trotter, 1982)

Type of source	Approximate luminance (cd/m², clear bulb)	Average rated life (hours)	Capital cost rank (1=costly)	DC source	Warm-up time (minutes)	Restrike time (minutes)	Colour appearance and rendition
Tungsten Filament	0^5 to 10^7	750 to 1,000	7	Yes			Warm, white to yellow, excellent rendition.
Tungsten halogen	2×10^7	5[a] to 2,000	4	Yes			Warm, white, slight yellow, excellent rendition
Fluorescent	5×10^4 to 2×10^5	500[b] to 30,000	3	Yes			Warm, white, excellent rendition
Mercury Vapour	10^5 to 10^6	16,000 to 24,000	6	Yes with limitations	7-9	3-10	Cool, bluish, average rendition
Metal Halide	5×10^6	10,000 to 20,000	2	Yes with limitations	2-5	10-20[C]	Cool, blue-white, good rendition
High-Pressure Sodium	10^7	12,000 to 24,000	1	Not advised	3-4	0.5-1	Warm, golden colour, fair rendition
Low-Pressure Sodium	10^5	10,000 to 18,000	5	Not advised	7-9	1-2	Warm, amber, poor rendition

[a] This is not general service lamp.

[b] The 500 hour lamp is not a normal source. The 30 000 hour lamp is a cold cathode lamp - not suitable for mines.

[c] Less if special circuits are used.

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Table 2 Mine Lighting (illuminance) standards in some countries (after Bell, 1983a)

Lighting location and minimum recommendation in lux (lm/m^2)							
Country	**Shaft bottom**	**Houses (engine, pumping, etc.)**	**Main Roads (Haulage)**	**Loading Points**	**Underground Offices**	**Locomotive Repair Area/Inspection Area**	**Coal Face**
Australia	20	0		20	100		
Belgiuim	20	25	10	20			
Canada	50	50	20	20	270	270	
Czechoslovakia	15	20	5	20			5
East Germany	30	80	15	40			
West Germany	30	40	15	40			
Hungary	60	20	2	40		20	10
Poland	50(s)	50(s)	2(s)	15(s)		50/100	2(s)
United Kingdom	70	30		30	60	50/100	
United States							15(s)
Surface Locations	100	100	100	100	400	400	

Note: Where a blank space exists for some locations, this does not necessarily signify that there is no lighting at these points but rather that no official recommendation has been made.

(s) = statutory

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