Mining By Candlelight
Crown Reserve Mine 1911

LIGHTING CONCEPTS
FOR CANADIAN MINES

by

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ABSTRACT

The importance of good underground lighting to the total environment of mining cannot be overemphasized. In addition to the obvious benefit of improved worker morale, good lighting practices probably reduce accident severity and frequency as well as increase production.

This project reviews current knowledge of the state of the art, presents measured data on luminance and reflectivity from several Canadian mines, and suggests additional areas in need of research. Examples of good lighting practices are given and suggestions to mine operators wishing to improve the mine luminance environment are made.

Several countries presently have codes regarding the level of illumination required in the underground working place, and it is probable that Canada will pass legislation in this area as well. Some thoughts are presented regarding what the code should contain and how it should be arrived at.

It is hoped that the material can be used as an aid to the mine industrial engineer and as a starting point for researchers who plan to carry out related work.

RESUME

L'importance d'un bon éclairage sous-terrain dans l'environment minier ne peut être sous-estimée. En plus d'améliorer le moral du travailleur, de bonnes pratiques d'éclairage réduisent probablement la fréquence et la sévérité d'accidents tout en augmentant le rendement du travailleur.

Cette étude passe en revue les connaissances actuelles sur l'état de l'art, présente des mesures de luminance et de reflectivité effectuées dans plusieurs mines canadiennes et suggère d'autres sujets de recherche dans ce domaine. Des exemples de bonnes pratiques d'éclairage sont décrits et des conseils pour l'amélioration de l'environnement lumineux d'une mine sont donnés.

Plusieurs pays utilisent présentement des codes décrivant le degré d'illumination requis dans les endroits de travaux sous-terrains; il est probable que le gouvernement canadien adopte bientôt de nouvelles lois dans ce domaine. Plusieurs commentaires sont donnés concernant la formulation et le contenue de telles lois.

Il est souhaité que ce matériel soit utile à l'ingénieur industriel des mines et serve comme point de départ aux chercheurs travaillant dans ce domaine.

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NOTATION

Notation is normally S.I. (Système International d'Unités):

CANDELA	cd
STERADIAN	sr
LUMEN	lm
LUX	lx
APOSTILB	asb
STILB	sb
FOOT-LAMBERT	ft.L
FOOT-CANDLE	f.c.
NIT	nt
METRE	m
FOOT	ft
MICROMETRE	µm
HERTZ	Hz
SECOND	s
YEAR	a
KELVIN	K
CELSIUS	°C

CHAPTER 1

INTRODUCTION

Underground lighting in Canadian mines generally is poor, particularly when compared with other lighting situations. Yet, the sense of sight is our most important sense. This lack of attention to mine lighting is a result of the unique nature of the work. With working places spread out often both laterally and vertically, particularly in base metal sulphide deposits, and with continual blasting in these working places, permanent installations are generally deemed impractical because of the costs of installation and upkeep. Consequently, the battery operated cap lamp is usually the most important single source of light. Although a tremendous improvement over the carbide lamp, it nevertheless gives little peripheral lighting, produces glare problems, only lights the immediate task, and is an extra weight for the miner to carry. The poor natural reflectivity from underground surfaces and, at times, the loss of transmitted light because of fog, dust or smoke all lower the efficiency of the available light. The problem is further compounded because neither government nor industry know just what constitutes good lighting in the mine environment.

Although economics will not allow the general level of lighting in a mine to approach the standard attained in an office or factory, it is possible to weigh costs versus benefits and greatly improve the lighting underground over that provided by vehicle headlights or the common cap lamp. Ideally, lighting would be designed based upon the visibility requirements of the various tasks to be performed. Some companies actually use this approach when designing lighting for permanent underground working areas such as underground garages, crusher stations, or shaft stations. This new approach to mine lighting based on visibility requirements is a better method than the usual practise of installing lights and then turning them on to see what the illumination level is. More research is needed, though, to determine task visibility requirements.

Good lighting is not only a matter of more light. It is also a matter of proper distribution of light. Light should not present irritating glare problems. It should come from the right direction, in the right quantity, of the right colour, and without introducing distracting sources of light to the eyes, or glare reflections in the work. This research project plans to show how current knowledge can be applied to the solution of problems of mine lighting design. It emphasizes those aspects of lighting design which affect the working efficiency and safety of the miner.

The report is divided into two sections. The first section, comprising Chapters 2 to 7, briefly outlines the state of the art as known to the present time. Units of measurement are carefully defined, a layman's guide to how the human eye functions is presented, and the science of measurement of underground lighting is outlined. The more common types of mine lighting systems encountered by the writer on visits to Canadian mines are described as well.

The second section, comprising chapters 8 to 11, present field measurements of illumination levels and both field measurements and laboratory measurements of reflectivity of commonly encountered underground surfaces. Since one sees by reflected light it is important to know the percentage of light which gets reflected into the eye in order to design a proper lighting installation. Measurements were taken in fifteen mines ranging from as far west as Flin Flon on the Manitoba-Saskatchewan border to Bathurst, New Brunswick in the east. General lighting practices were noted and ideas were exchanged with several mine personnel. Many practices noted are incorporated throughout the report.

The current concern for the human environment shows no signs of abating. Sooner or later, provincial governments will establish standards of mine illumination levels just as they have established standards for toxic gas emission, dust and noise levels. A basis for establishing such a standard is provided in the second section of the report as well. It should only be construed as a suggestion to industry and a starting place for other investigators. More experimental work is required in the field before lighting standards for mines can be expressed with any degree of confidence.

The normal order of presenting the results of an experimental study is:

1. the job proposal
2. the tools and techniques to do the job
3. the nature and significance of the work done.

Since this report is not confined to any one experimental study but presents instead a broad overall view of lighting concepts for Canadian mines, the traditional approach was not followed. Experimental work and personal observations are included in the appropriate section or sub-section of the report. In this way the observations, experimental work, and conclusions drawn, expand on the topic under discussion. To preserve continuity in the main body of the report, results of experimental work are briefly summarized in table form. Additional findings are either presented in the appendices or are available from the files of the Department of Mining and Metallurgical Engineering at McGill University.

It is hoped the material will be helpful to civil engineers engaged in tunnel projects, as well as to mine industrial engineers and mine planners. Since several areas of research remain untouched it is further hoped the work will serve as a starting point for other researchers planning to carry out allied work.

SECTION I

STATE OF THE ART

CHAPTER 2

LIGHTING UNITS

2.1 Choice of Units

Canada has embarked on a program of converting to S.I. units (Système International d'Unités). Consequently, the S.I. system of units was chosen when possible. Since S.I. is not in regular use as yet it has also been necessary to express many of the units in terms of the imperial system or in units other than recognized S.I. units. This occurs where statutory regulations or original research results are quoted. It also occurs because an official S.I. luminance unit has yet to be chosen.

TABLE 1

S.I. UNITS RECOMMENDED BY THE CANADIAN STANDARDS ASSOCIATION

	Physical quantity	Name of unit
Basic S.I. unit	Luminous intensity	Candela
Supplementary unit	Solid angle	Steradian
Derived units with special names	Luminous flux	Lumen
	Luminous energy	Lumen, second
	Illumination	Lux
	Luminance	None given (apostilb used in this report)

2.2 Plethora of Units

There is a great deal of confusion in the literature on the use of lighting units. This is due to several factors. Some countries work in imperial units while other countries report in metric units, and there is quite a mix of units in both systems. In addition certain countries are gradually changing over to S.I. units. A further source of complication arises from the fact that light measurements can be quoted either in fundamental units of illumination expressed in terms of luminous intensity per unit area or in units of luminance related to illumination through reflectivity. This means there are two approaches to light measurement; one based upon the light source (illumination), the other based upon the receiver or eye[1] (luminance).

The luminance unit is required to relate what the eye sees to the amount of light supplied. Luminance units have both metric and imperial counterparts. Although a fundamental S.I. unit has been chosen for illumination which is the lux, no equivalent luminance unit has as yet been officially chosen. The result is that writers use unofficial units for reasons of convenience. In this report the luminance unit chosen was the apostilb which has a good chance of receiving S.I. sanction (3).

Further confusion results from the use of a double set of illumination units. One is the total illumination put out by a light source related to the power of the source at the source. The other is the illumination put out by the source in terms of luminous intensity per unit area of surfaces receiving light. Again there are metric and imperial counterparts (11, 33, 64).

In order to assist the reader in finding his way through this confusing situation, the following sections are presented.

2.3 Definitions of Fundamental Units

The Candela is the luminous intensity of 1/60 of 1 cm^2 of projected area of a blackbody radiator at the temperature of solidification of platinum, 2045 K. This is a fundamental S.I. unit and takes the place of the former candle. To all intents and purposes the units are synonomous. (A blackbody is a temperature radiator of uniform temperature whose radiant emittance in all parts of the spectrum is the maximum obtainable from any temperature radiator at the same temperature.)

The Lumen is the unit of measurement of luminous flux. Imagine an isotropic point source of light of one candela and let a system of unit radius be described around this. Then each unit area will receive the same amount of luminous flux and this is the lumen.

The Steradian is a measure of the solid angle at the centre of a sphere. If the area of spherical surface is equal to the square of the radius, the subtended solid angle is a steradian.

The Talbot is the luminous energy delivered by 1 lumen in 1 second.

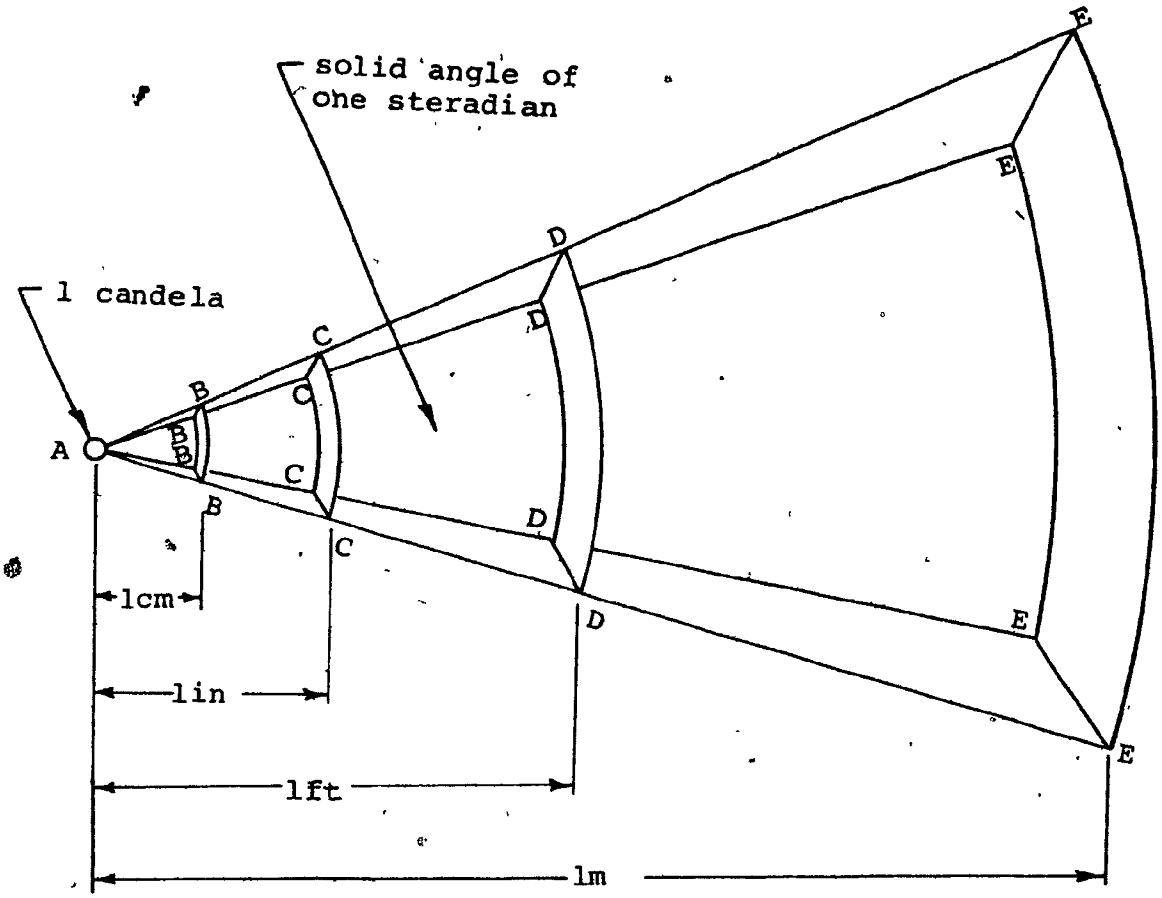


FIGURE 1: UNITS OF ILLUMINATION AND LUMINANCE

A = 1 candela in all directions
Point A to any B is 1 cm. BBBB = 1 cm^2
Point A to any C is 1 in. CCCC = 1 in^2
Point A to any D is 1 ft. DDDD = 1 ft^2
Point A to any E is 1 m. EEEE = 1 m^2

The luminous flux falling on either BBBB, CCCC, DDDD or EEEE is one lumen by definition. The surface area of a sphere is $4\pi r^2$ so that the total luminous flux emitted is 4π lumens or 12.56 lumens.

2.4 Units of Illumination

The illumination on BBBB is 1 lumen/cm^2 = 1 phot

The illumination on CCCC is 1 lumen/in^2 = 1 inch candle.

The illumination on DDDD is 1 lumen/ft^2 = 1 foot candle

The illumination on EEEE is 1 lumen/m^2 = 1 lux

The lux has also been referred to as the metrecandle.

Since 1 m = 3.28 ft. it follows that

$$1 \text{ footcandle} = \frac{1 \text{ lumen}}{ft^2} \times \left(\frac{3.28 \text{ ft}}{1 \text{ m}}\right)^2 = 10.764 \text{ lux}$$

Similarly 1 lux = 0.0929 lm/ft^2

The conversion 1 footcandle = 10 lux is often used. This means that the illumination on DDDD is approximately 10 times greater than the illumination on EEEE.

For light sources themselves the phot is a more convenient unit.

1 phot = 10 000 lux

1 lux = 10 milliphot

2.5 Units of Luminance

Luminance is a measure of the brightness of a surface. As the luminance corresponds to the light emitted from the surface it normally depends on the ability of that surface to reflect light. For lamps and other light sources the luminance is a measure of the light emitted. Lighting engineers find the luminance unit essential in their work because this is what the eye sees. The unit of luminance is related to the unit of illumination by the following:

LUMINANCE = ILLUMINATION X REFLECTIVITY

For example, an underground road surface with a reflectivity of 0.09 receiving an illumination of 100 lux has a luminance of 9 asb. If the reflectivity were 100%, then it would have a luminance of 100 asb.

If, in Figure 1, we assume all of the luminous flux from A (1 candela in all directions) is reflected in a perfectly diffuse manner by BBBB-CCCC-DDDD or EEEE in turn, then

BBBB reflects a luminance of 1 lumen/cm^2 = 1 lambert

CCCC reflects a luminance of 1 lumen/in^2 = 1 inch lambert

DDDD reflects a luminance of 1 lumen/ft^2 = 1 foot lambert

EEEE reflects a luminance of 1 lumen/m^2 = 1 apostilb

It follows that 1 ft.L = 1.076 millilamberts = 10.76 asb.

This is analagous to 1 f.c. = 1.076 milliphots = 10.76 lux.

As well as expressing luminance in terms of lumens per unit area it can be expressed in terms of candelas per unit area

1 candela/cm^2 = 1 stilb = 2919 ft.L = 31 416 asb.

1 candela/m^2 = 1 nit

The following relationships can then be derived.

1 lambert = $\frac{1}{\pi}$ candela/cm^2 = 0.3183 sb

1 footlambert = $\frac{1}{\pi}$ candela/ft^2 = 0.3183 cd/ft^2

1 apostilb = $\frac{1}{\pi}$ candela/m^2 = 0.3183 nt

As a rule, the apostilb is used to indicate the luminance of walls, floor, back and other non-specular objects while the stilb is used to indicate the power of the light source. The following light sources, arranged in order of size of their luminances, are presented so that one can get a feel for the stilb unit(1).

TABLE 2

LUMINANCE OF LIGHT SOURCES

Moon	0.25 sb
Clear sky	0.4 sb
Fluorescent tubes	0.45-0.65 sb
Lighted candle	0.7-0.8 sb
Oil lamp	0.6-1.5 sb
Electric bulb	70-1000 sb.

2.6 Use of I.E.S. (Illuminating Engineering Society) Units

The great majority of the literature references cited quote in IES units so that it is necessary to be conversant with these units as well. The three most important units are the foot lambert, the foot candle and the candela per in^2.

A diffusing surface of uniform brightness reflecting or emitting 1 lumen per sq.ft. when viewed from a designated direction has a brightness of 1 ft.L. Similarly, one candela over one square inch has a brightness of 1 cd/in^2. The ft.L is normally used for brightness of illuminated surfaces whereas the cd/in^2 is used for high brightness such as a source of light.

The difference between a foot-candle reading and the corresponding foot-lambert reading is the light absorption of the surface whose brightness is being measured. Using the previous example, an underground road surface with a reflectivity of 0.09 receiving an illumination of 100 f.c. has a luminance of 9 ft.L. If the reflectivity were 100%, then it would have a luminance of 100 ft.L.

Table 3 has been worked out for ease of conversion.

TABLE 3

UNIT CONVERSION FACTORS

	Foot Lambert ft.L	Apostilb asb	Candela/m² cd/m²	Candela/ft² cd/ft²	Candela/in² cd/in²
	Foot Candle (f.c.)	Lux	Nit (nt)		
ft.L	-	0.0929	0.2919	3.142	452
asb	10.76	-	3.142	33.82	4870
cd/m²	3.426	0.3183	-	10.76	1550
cd/ft²	0.3183	0.02957	0.0929	-	144
cd/in²	0.00221	0.0002	0.00065	0.0069	-

To convert the top row to the side column multiply by the box factor. Since most light measurements are rough measurements it is customary to round off. For example:

$$1\ cd/m^2 = 1/3\ ft.L = 3\ asb = 0.1\ cd/ft^2$$

$$1\ ft.L = 10\ asb = 3\ cd/m^2 = 0.3\ cd/ft^2$$

Table 17 is provided to convert from values in customary I.E.S. units to S.I. units. No conversion from S.I. to I.E.S. is given since all thought should be given to making S.I. the one system of units.

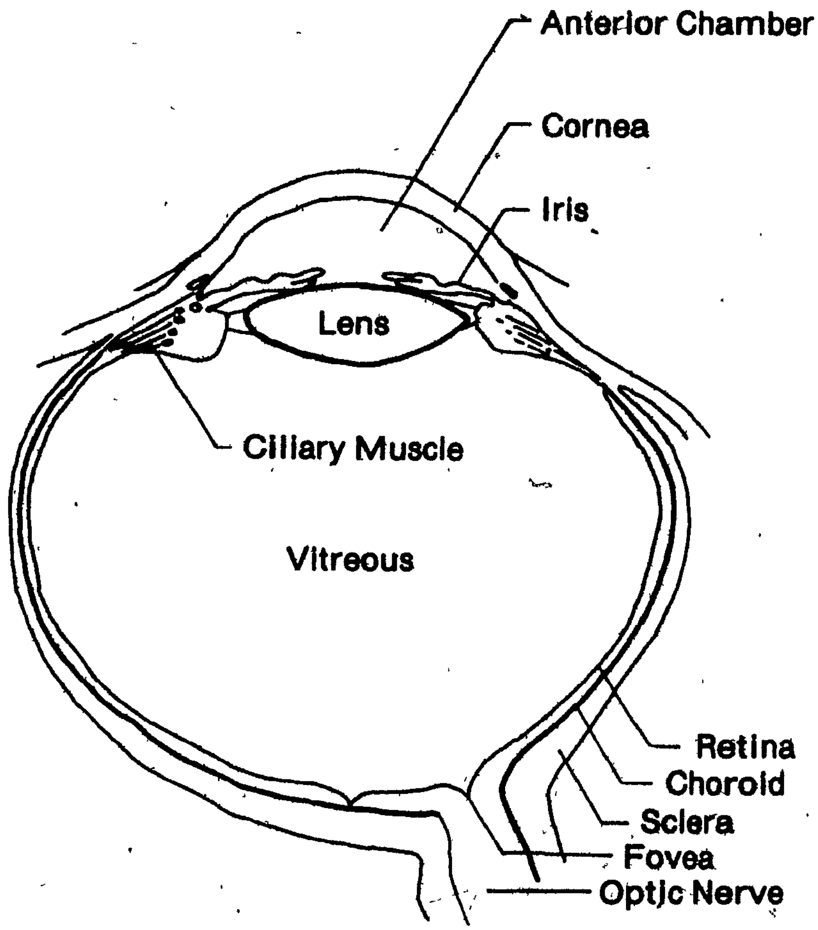
CHAPTER 3

OPERATION OF THE EYE

3.1. The Vision Process

The human eye is sensitive to a very wide range of light intensities, extending from a few lx in a dark room to 100 000 lx in bright sunlight. Light intensity in the open varies from 2000 to 100 000 lx during the day. The usual variations during the night and underground in artificial light lie between 5 and 500 lx. Although the eye is able to make use of a wide range of light levels, there are certain optimum conditions in which it works best. Since the aim of good underground lighting is to provide an optimum seeing condition, some knowledge of the operation of the eye should be acquired before attempting any underground lighting design.

Figure 2 shows a horizontal section of the human left eye. The process of vision is a combined operation of eye, nerve, and brain with the inner lining of the eye cavity being an extension of the brain. It can be imagined, for simplicity's sake, to contain numerous small organs, which by reason of their shape are called rods and cones. There are about 130 million rods and about 7 million cones. These are arranged end on so that they form a mosaic over the retina. They are not uniformly



A Horizontal Section of
The Human Left Eye

Figure 2

distributed. The central region of the retina, called the fovea, consists of cones only. A small area surrounding the fovea, called the macula, has a high cone concentration. Outside the macula the proportion of cones is less and becomes progressively smaller towards the periphery of the retina where rods predominate.

In the central retina area, every cone communicates its signal to the brain individually, each receptor being connected to the brain by a separate nerve fibre. An image received in these areas can therefore be transmitted in detail. If we wish to see an object clearly we look directly at it so that its image falls on the fovea, the most acute region of the retina since this is where the cones are located. This generalization must be modified when dealing with low levels of illumination.

These cones are also the seat of colour perception. Only radiations with wavelengths between 0.4 and 0.7 μm produce a visual sensation, including colour. 0.4 μm is the violet end of the spectrum and 0.7 μm is the red end. Colour of light may be due to a combination of a continuous series of radiations of all wavelengths in varying proportions as with light from a tungsten lamp. It could also be a combination of varying proportions of a limited number of radiations known as a broken spectrum as found with a mercury vapour lamp, or it could be due to the presence of only one wavelength as with a sodium lamp. The cones of the eye are not equally sensitive to all colours and in addition, the dark surfaces of the rock face absorb different proportions of different wavelengths. Rays in the blue-green band of the visible spectrum are generally absorbed the least and hence a high proportion of the light is reflected.

Outside the macula each receptor does not have its own nerve fibre. Each signal path is shared by a group of receptors. Consequently, in the peripheral retinal areas, a detailed image cannot be transmitted to the brain. Also, the rods are not colour-sensitive but have an extremely high light sensitivity, so that their function is to permit seeing at very low levels of light. Thus, the eye sees best centrally in bright light, its resolution is very high and it sees colour, whereas in low light, resolution is poor, colour vision is absent, and vision, though nowhere good, is better away from the centre. To see in the dark, then, it is best to look slightly away from the object.

The arrangement of the rod receptors has a special purpose. Because many rods are linked to one nerve path, there is a good chance that an image falling upon the periphery of the eye will register a sensation. Peripheral illumination is thus important from a safety standpoint for the underground worker, particularly where moving machinery or open holes could constitute a hazard.

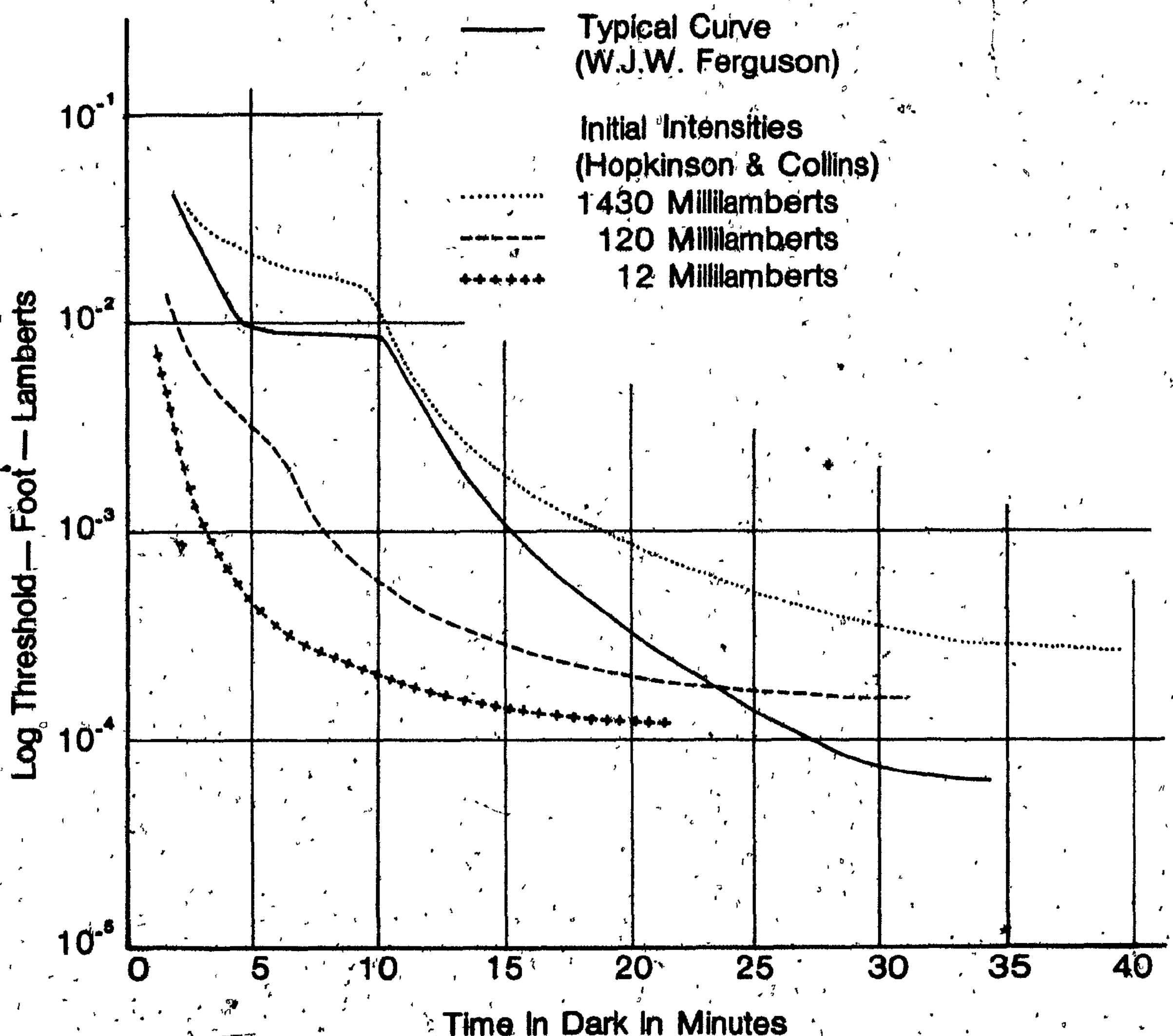
3.2 Adaptation of the Eye

Although the human eye is sensitive to a very wide range of light intensities it cannot respond to this full range at any one time. Since adaptation to the light or the dark does not take place instantaneously, this has special significance to underground mining. To illustrate, a scoop tram operator driving up a ramp can be momentarily blinded on arriving at surface on a sunny day. The same driver would experience a loss in seeing efficiency if, after his eye was adapted to sunlight, he then entered the ramp. This obviously creates a temporary hazardous situation. Fortunately a large degree of adaptation may occur when moving from one location to another, the maximum level of adaptation being about 50 to 1. By increasing the number and intensity of lamps and decreasing the spacing between lamps as one proceeds up the ramp the eyes can have time to adapt. Knowing the speed of the vehicle on the ramp and knowing the adaptation rate, the ramp lighting installation near the entrance can be designed. Using photocells it would be possible to design a ramp lighting system which would automatically adjust its light to parallel changing daylight conditions (82).

The adaptation process takes place in stages. One stage involves photochemical transformations in the retina, some taking place quickly while others take place more slowly. Dark adaptation can be determined as a function of the contrast threshold, that is, the least contrast above the adaptation level which can be detected. The progress of adaptation follows curves of the type shown in Figure 3 (1,3,7,32).

The first portion of the curve represents the dark adaptation of the cones which generally take one to five minutes. The discontinuity in the curve represents the point at which the rod mechanism comes into play. For the rods to be completely dark adapted generally takes another ten to thirty minutes. If one goes into a darkened theatre for the first few minutes vision is difficult for anything other than the screen. Then suddenly objects around become visible. This is the point where the rod mechanism takes over and corresponds to the sharp drop in the dark adaptation curve. Complete adaptation may only be reached in an hour with 80% being obtained in about 25 minutes.

Light adaptation is faster than dark adaptation but may still need up to an hour to become complete. The first phase lasts only 0.05 s, during which time the sensitivity of the retina is suddenly reduced to one-fifth of its original value. The second phase proceeds at a slower rate and, like dark adaptation, it is determined by a change in equilibrium between breakdown and synthesis of the photo-sensitive materials of the retina. The sudden reduction in light sensitivity affects the whole retina.



Curves of Dark Adaptation

Figure 3

If the object being looked at contains a large bright or dark area, a local adaptation will occur in a portion of the retina. There is, in addition, an effect on all of the retina. Adaptation of one eye affects the other eye to a certain extent as well. This has important implications in this study where only one eye was used with various types of visual photometers. Since adaptation is only partial in the less illuminated eye, the effects of sudden dazzling as with a cap lamp shone in the eyes, can be reduced by closing one eye. The closed eye retains partial dark adaptation and recovers rapidly (26,32,57).

From these observations, some facts to bear in mind when designing underground lighting can be stated. Illumination and surface brightness should be of fairly even intensity throughout the visual field. The general level of illumination should not change rapidly, thereby giving time for adaptation to occur. One should design for dark adaptation rather than for light adaptation since dark adaptation is slower than light adaptation.

3.3 Glare

Glare can be thought of as light in the wrong place. The main cause of glare is light shining directly on the eye instead of the object we wish to see. The pupils of the eyes involuntarily dilate and contract depending on the amount of light reaching the eye. In the dark the pupils are dilated and susceptible to glare. Increasing the illumination from 0.5 lx to 100 lx would cut the pupil area in half but the eye would feel the strain. This discomfort, caused by a major disturbance of the adaptive state of the retina because of light in the wrong place, is known as glare.

Three types of glare are recognized. Relative glare is caused by too strong a contrast in the visual field. Absolute glare is due to such high illumination that adaptation is not possible. Adaptive glare occurs when adaptation to a given level of illumination has not yet been reached.

The types of glare can be illustrated by examples. In a mine relative glare can occur when a cap lamp is shone into the eyes. With miners the orientation of cap lamps to avoid directing the light into each other's eyes is a common courtesy. After a short time in a mine a miner soon learns of the annoyance of a glaring cap lamp and responds by tilting the head downwards, rotating it to the side, or if on a mancage, keeping the lamp off or letting it hang from its cord placed aroung the back of the neck. Absolute glare can be experienced in dazzling sunlight on open water but is never a problem underground. Adaptive glare could occur when a teletram driver breaks from a ramp into the open during daylight.

Frequent fluctuations in light values cause the eyes to constantly readjust themselves with a marked loss in seeing efficiency. The pupils contract when hit with bright light and do not dilate for quite some time. Thus with intermittent glare the eye never becomes fully adapted and cannot provide good vision within shadowed areas. Marked contrasts in lighting values in the working area must be avoided and small brightly lit areas are a definite disadvantage, as they reduce the worker's effective vision when he transfers his gaze outside those areas. This means that the danger of glare is greater when the general level of illumination is low. Consequently, illumination levels should be kept high. To illustrate, a car headlight on high beam is hardly noticeable during the day. To increase the background brightness, whitewashing or shotcreting can be resorted to.

To avoid or reduce glare several other principles can be stated. The shorter the exposure to glare the more quickly will the original state of adaptation be reached. An experienced driver, driving at night, will avoid looking at the headlights of an approaching vehicle. A source of light above the line of sight is less distracting than one which lies to the side or below it. The angle between the horizontal line of sight and a line from the eye to the light source should be greater than 30^{o}. No point light source should appear in the visual field of the operator.

In practice this is very difficult to achieve since the tungsten filament lamp is used so commonly underground. In many applications the high brightness of a tungsten filament is a disadvantage rather than an advantage. The degree of glare depends upon the relative brightness of the source, increases with increase in area of the source and is worse where the source is close to the line of sight. To reduce the apparent brightness and hence the glare of the filament lamp without lowering its efficiency, inside frosted bulbs are often used. This has the effect of increasing the surface area of the source so that the illumination per unit area is lowered. If the eye fixates on a point on the bulb the glare effect is lessened. Bulbs coated on the inside with a white silica powder look completely white and uniformly bright with only a very slight reduction in over-all lamp efficiency. The light appears to be generated at the surface of the bulb rather than from the filament. Diffuse reflectors designed to screen the light, if properly installed, will ensure that the light source will usually not appear in the visual field of the operator. Unscreened lights should not be used.

Other factors are worth noting in an attempt to reduce glare. The effect of glare is less severe when yellow or yellow-green light is used, compared with white light of the same intensity. If filters are employed to achieve this light, a considerable proportion of the total amount of light is absorbed. Highly efficient light sources are on the market though which produce a yellow light without the need of filters. In addition, care can be exercised to avoid glare from reflection. Many mines paint their travelways, lunchrooms, etc. with a highly reflective metallic paint, presumably since it is difficult to mark up with graffiti. The use of polished surfaces or specular materials on machines or walls should be avoided and a flat paint chosen when possible. In addition, to avoid glare from reflection, the work place should be so positioned that the most frequently used lines of sight do not coincide with specular reflections. When the angle of the light source in relation to the task is such that the light rays can be reflected directly into the viewer's eye, veiling reflections may result. They are called veiling reflections because they have the effect of pulling a veil over the detail. One reacts instinctively to this by moving the head until the annoying light image disappears. Thus the angle of the light source in relation to the task is changed so that specularly reflected light is directed away from the eye. If the geometry is understood the veiling reflection problem can be controlled (18,27,29,34,35,76,94,112).

If glare sources are introduced in conjunction with mine illumination, the increased safety benefits from the increase in illumination can be jeopardized by introducing eye adaptation problems. The designer must realize the implications of glare, the importance of glare control, and the steps which can be taken to ensure that light is not getting into the wrong place.

3.4 Fixation

In order to look or fixate, the brain and eye together make a decision to concentrate attention on one area in order to gather visual information. In performing this act the eye makes scanning movements or saccades which permit the searching to be done most efficiently. This act is normally done without conscious effort even though the eye or head may be turned in the direction of the wanted area.

The eye is distracted from voluntary fixation by areas of high brightness, contrast, colour or by combinations of these. This is because there remains in the eye an effect known as phototropism, the involuntary tendency for the eye to orient towards the light. Approaching miners' cap lamps in a drift or oncoming headlights in a haulageway would create phototropic distractions. Distractions of this type can impede task performance since it is more difficult to fix attention on a darkened area.

The implication to mine lighting design is that point sources of light and areas of high contrast should be avoided so that the eye can focus its attention on what the brain commands without having to compensate with conscious effort.

3.5 Visual Acuity

Visual acuity is the ability to discriminate fine details coupled with depth perception. It can be thought of as a measure of the resolving power of the eye. As a rule the various functions of the eye are not stressed to their limits but in certain mining activities such as scaling the back, collaring a hole, or barring a chute, maximum demands can be made on visual ability.

Researchers in this area have made some interesting observations. Visual acuity increases with the level of luminance in the visual field and reaches a maximum at 5000 asb. Between 1 and 5000 asb it increases by more than 150%. Visual acuity increases with the difference in luminance between the object and its immediate environment. Where the two luminances are similar, small changes in relative values can make great differences to visual acuity. Visual acuity is better with dark signs or objects on a light background than with light signs or objects on a dark background (1,3,6).

3.6 Contrast

Different researchers have defined contrast in different ways. In the mathematical context in which it is used here, it is equal to the brightness of the background less the brightness of the detail divided by the brightness of the background. It thus is a physically measurable quantity. Contrast sensitivity is the ability of the eye to perceive minimum differences in luminance.

It is of particular importance in mining since in a mine the surfaces tend to appear grey, have an indistinguishable hue, and reflect light rather uniformly. A boundary is evident by means of the relative luminosity between the adjacent areas. If, for example, there is little luminance from the floor around a millhole, a worker could step into the hole by mistaking it for the floor. The ease and accuracy with which workers can safely perform visual tasks depends upon the contrast between the detail and the background upon which it is viewed.

Research has shown that the optimum conditions for vision are greatly dependent on variations in contrast (37). Up to a certain point, the more the contrast in brightness the better we can see. Contrast sensitivity is greater when the outer parts of the visual field are darker than the central ones. The maximum contrast sensitivity is obtained with a central luminance of between 1200 and 1500 asb and a luminance of 100 to 300 asb in the periphery of the visual field. In addition it has been found that contrast sensitivity is greater for small areas than for large ones (25,30,31).

With more light, the eye is more sensitive and requires less contrast to see detail. This is the reason that higher and higher illumination levels have been achieved. Experiments have shown that a 1 per cent loss of contrast requires a 10 to 15 per cent increase in illumination to maintain the same visual performance. Contrast sensitivity has been found to be greatest in a range between 200 and 1000 asb (30).

Several specific suggestions have been made by authorities to increase contrast sensitivity. The surface brightness of all large surfaces and objects in the visual field should be as nearly equal as possible. In the central and middle parts of the visual field contrasts of surface brightness should not exceed a value of -2 (3:1). Between the central and outer parts of the visual field, contrasts should not exceed a value of -9 (10:1). This contrast between detail and background can often be controlled by controlling the direction from which light strikes a task. Bright surfaces should be in the centre of the visual field and darker ones on the periphery.

The designer of underground lighting should be aware of the importance of contrast. Merely by having fixtures mounted as high as practical and in a uniform manner to insure that brightness is fairly evenly distributed would greatly aid the eye to achieve a state of high contrast sensitivity.

3.7 Speed of Perception

The speed of perception is the time which passes between looking at an object and its visual perception.

The speed of perception increases with the average level of luminance and with the degree of contrast between the object and its environment.

Many underground accidents can be attributed to a slowness in speed of perception or a lack of speed of perception. Being struck by a moving train or by falling loose or stepping in front of a moving scraper are some examples that come to mind. Low levels of illumination were undoubtedly a contributing factor and should be given serious thought particularly since these types of accidents also rate high on the severity scale. Particularly where moving machinery is involved, the level of illumination should be kept high based on safety considerations alone.

3.8 Occupational Nystagmus

All types of occupational nystagmus have one thing in common: the inability of the eye to maintain fixation focus under certain circumstances. A common symptom is a spasmodic movement of the eyes, rotary or from side to side. Several factors seem to be involved in the disorder; employment of the eyes in a constrained position, the speed at which objects are travelling, the colour and shape of the objects, the amount and type of illumination, number of rest periods, and finally the degree of fatigue of the individual involved (32).

A form of nystagmus, known as miners' illness, has been common since mining began. In Britain it was prevalent among middle aged or elderly coal miners who had worked for a period of twenty-five to thirty years underground. Its physical symptoms consist of difficulty of seeing in the dark, excessive sensitivity to and intolerance of glare, and a rhythmic oscillation of the eyeballs. Other general disorders are headaches and dizziness. Poor illumination seems to be the predominant cause of this problem. At one time it was estimated that more than 70 per cent of all underground miners in Europe and Great Britain suffered from this disorder. Many of the miners were never able to work underground again (70). The incidence of the disease has fallen considerably with the improvement of underground lighting. Where cap lamps are used, miners' illness is virtually unheard of.

Another form of nystagmus is known as conveyor belt sickness. Diagnosed as occupational optokinetic nystagmus, this eye disorder results from the eye's inability to change its fixation point rapidly enough to keep pace with the muck on the moving belt. The symptoms are similar to the first stages of carbon monoxide poisoning; giddiness, fainting, nausea and general mental confusion (70). When the eye follows objects moving along a conveyor belt, it is constantly establishing new focus fixation points. The eye will fix on one object, follow it for a short distance then change its fixation to another object. As the speed of the belt increases, the number of fixation points per minute must also increase. When the objects move more rapidly than the eye can establish focus fixation points, involuntary contractions occur in the eye muscles. These contractions cause the eyeballs to oscillate rapidly, parallel to the direction of conveyor belt travel. This motion is usually jerky or pendular, and the individual cannot control it. As a result, the sense of balance is affected, which in part, triggers the other unpleasant symptoms. Cagetenders can be similarly affected by watching the wall plates flash by as the cage ascends or descends in the shaft. It is entirely possible that occupational optokinetic nystagmus may be responsible for some of the illness which at present cannot be traced to a known cause.

The most commonly used remedy is complete rest, and the time of recovery varies from a few hours to several weeks, depending upon the individual and the severity of the attack. Conveyor belt attendants and cagetenders should be informed of the possible consequences of optokinetic nystagmus so that they can avert their gaze from rapidly moving visual sensations. A further remedy is to make sure the cage is completely enclosed or that moving parts are covered from view.

3.9 Flicker

Flickering light can have harmful effects. The eyes can become fatigued. With flickering at about 10 Hz, 10% of those tested have symptoms anywhere from reduced attention, headache, nausea, to a complete epileptic seizure. Flickering between 5 and 25 Hz in particular should be avoided as it is bad for the worker.

Investigations by Grandjean (1) have shown that flickering of fluorescent lights causes an increase in physiologically measurable fatigue and a measureable decline in performance. This flickering can be caused by defective or old tubes. This slow, perceptible flickering frequency occurs particularly at the ends of the tube.

Because they use alternating current, fluorescent lights produce an alternating intensity of light with a frequency of 60 Hz. This is faster than the subjective fusion frequency of the eye and is not noticeable. On the other hand, it is visible on moving objects, particularly if they have high specular reflectivity. This phenomenon is called the stroboscopic effect. It is greater with daylight tubes than with white or warm tones. Invisible flickering of 60 Hz and also the stroboscopic effect can be greatly offset by using two or more fluorescent tubes in each light and having the phases made to alternate by the use of suitable appliances.

Alternating bright and dark surfaces are worse than continuous marked surface contrasts. This occurs at work when the gaze has to wander rhythmically from light to dark surfaces, when light and dark surfaces pass by on a conveyor belt, when shining and moving machine parts appear in the visual field or when a light source is flickering.

As mentioned previously in Section 3.2 there is a certain delay before the retina can adapt to changes in intensity of the incident light. With alternating brightness a constant over or under exposure of the eye is present. Physiological investigations have shown that a rhythmical change of two surface brightnesses with a contrast value of -4 causes a decline in visual performance which is of the same magnitude as reduction of the light intensity from 1000 to 30 lx.

To avoid alternating surface brightness certain precautions should be taken where possible. Moving machine parts should be enclosed. Unavoidable brightness in the working visual area should be offset by suitable background colour and careful illumination. Non-flickering lights should be provided.

3.10 Vision in the Older Worker

Young workers have the best vision in every respect. Compared to older workers their maximum acuity is greater, their range of adaptation is greater, they can accomodate to objects very close to their eyes, they can see clearly at a distance, and they generally are not troubled by scattered light.

Luckeish (6) quotes figures obtained by averaging a number of surveys. Assuming the relative visual acuity of average eyes for the age of twenty years to be 100 per cent, at the age of forty it has declined to 90 per cent, at sixty it is 74 per cent, and at seventy years it is only 47 per cent. This decline in acuity of vision can be countered by increasing the illumination on the visual task. Several researchers have shown that in order to maintain a given degree of visual acuity in all age groups, the illumination on the task for the older groups must be progressively higher than that for the younger groups. Fortuin (96) has shown that, if the light requirement of a 40 year old for reading a book is taken as 1, then the light requirement for different ages is as follows:

10 - 20 years	0.3 - 0.5
20 - 30 years	0.5 - 0.7
30 - 40 years	0.7 - 1.0
40 - 50 years	1.0 - 2.0
50 - 60 years	2.0 - 5.0

To read clear print, a 60 year old man generally needs 15 times as much light as a 10 year old boy. Bodmann (23) in a comparison between performances of a 20 - 30 age group and a 50 - 65 age group found that levels of performance achieved by the older subjects with illumination levels of 100 to 400 lx were matched by the younger ones in an illumination of only 2 to 5 lx.

Decline in visual performance is not the only feature of advancing age. It is known also that from the middle or late twenties muscular strength diminishes, and that hand and foot reaction times increase from the age of twenty onwards, and the speed of manual movement decreases. There is thus a combination of factors which are all conducive to placing a man in a greater hazard with advancing years, but the detrimental effects of these factors can also be countered to some extent by improving the lighting environment.

All investigators, Weston (66), Fortuin (96), Bodman (23), Roberts (7), Mrs. Blackwell (19), agree that older people see less well than younger people and derive more benefit from higher lighting levels, but, according to Weston, an increase in illumination does not enable an old man to compare with a young man in visual performance, and that in fact it is impossible to compensate completely for the failing visual powers.

Since controlled laboratory tests under idealized conditions do not necessarily indicate the true practical situation, it is probably meaningless to indicate in a code of mine lighting a factor by which the illumination should be multiplied in relation to the age of those working under it. Older workers are well known to be capable of very high degrees of skilled performance, and their handicap is not always as great as the investigations would suggest. The older worker has greater experience.

He can make intelligent guesses at detail which he may not be able to see precisely such as collaring a hole so that in practise he may have an overall visual capacity greater than that of a younger worker. Nevertheless the age of an employee is a factor and the mine lighting designer should consider the older eye.

CHAPTER 4

LIGHTING, ACCIDENTS AND PRODUCTION

4.1 General

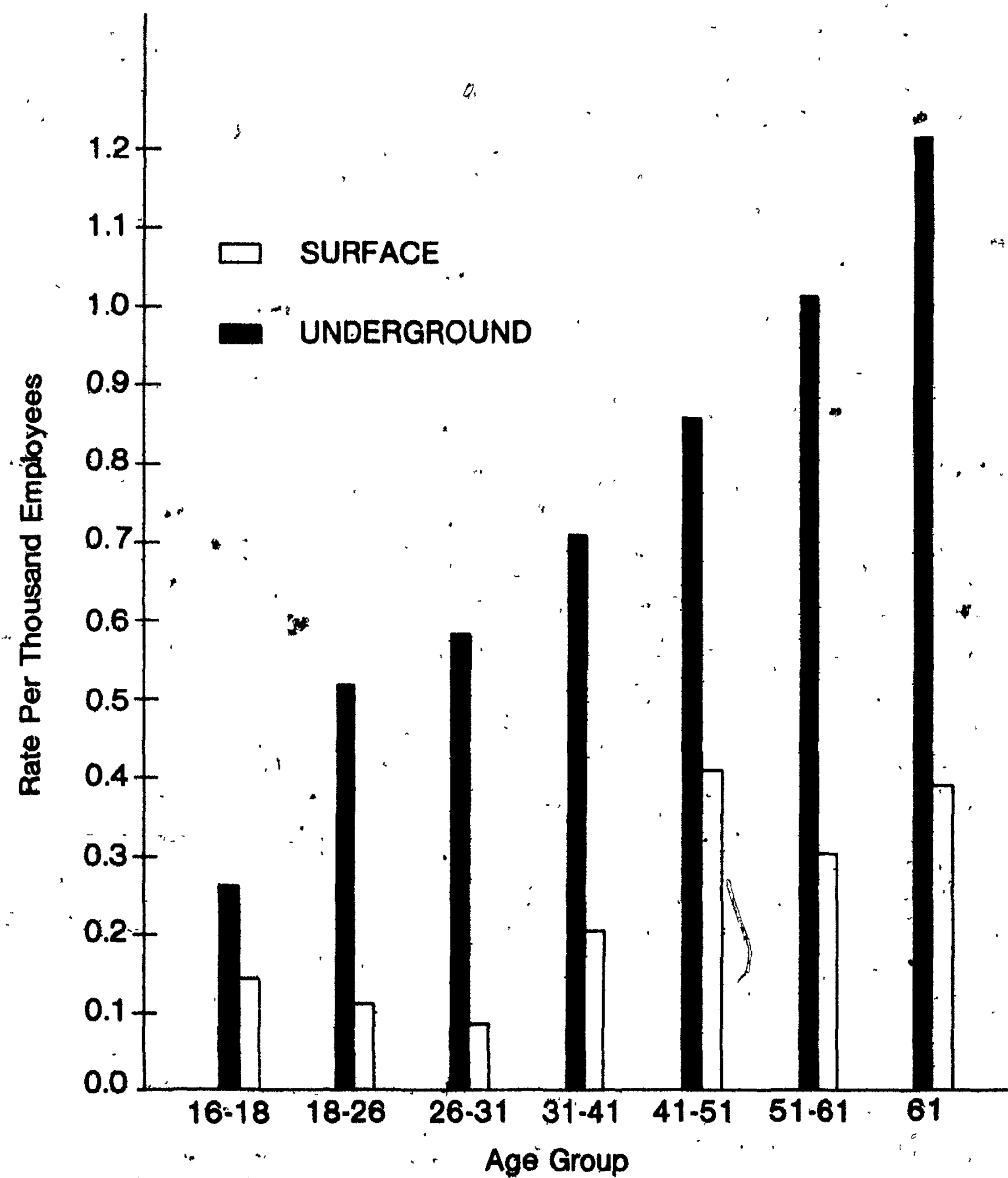
Progress in mine lighting in Canada has been slow. Good lighting systems are expensive and generally speaking it is difficult to convince the mine operator that more attention to mine lighting will prove beneficial to him. If one could prove conclusively to the operator that production measured in t/man shift would increase with improved illumination, costs could then be justified. Similarly, if one could prove that increased illumination would result in decreased accident severity and frequency with a resultant lowering of workmen's compensation rates, this would be an added incentive. Since the mining industry is plagued with a shortage of skilled miners, an attempt to show a correlation between the level of illumination and worker morale and hence turnover rate, might be justified.

One would expect that better lighting will increase output, reduce accidents, and improve morale but it is not easy to discover facts which can help prove either result. The direct effect of lighting on underground efficiency or safety is hard to measure. This is because a great many variables besides lighting affect production and safety. In a working mine, it is not possible to hold all these variables constant in order to determine the effect of lighting alone. The indirect effect such as the raising of individual morale by improvement in the visual environment, is very largely a matter of speculation.

Several laboratory experiments have proven conclusively that production increases and fatigue decreases with improved illumination (8). It is known too that the psychological effects of good lighting have resulted in improved morale in certain surface factories (1). Further studies prove highway accidents decrease with improved illumination (24). A similar result has been measured in factories (1). The half dozen or so reports relating to accidents or production in mines as a function of illumination lead one to conclude that better lighting has a definite effect on efficiency and safety (Sec. 4.2). It is an area of research though which remains largely unexplored.

4.2 Lighting and Accidents

An indirect proof of the importance of visibility and its relation to accident rates has been presented by Roberts (7,58). He uses a comparison of the fatality rates in the various age groups employed underground and on surface. It is known that visual performance deteriorates with advancing age and that this deterioration can be countered by improving the lighting environment. Fatalities increase considerably in the older underground worker in spite of the fact that most of these men are employed in the safer jobs.



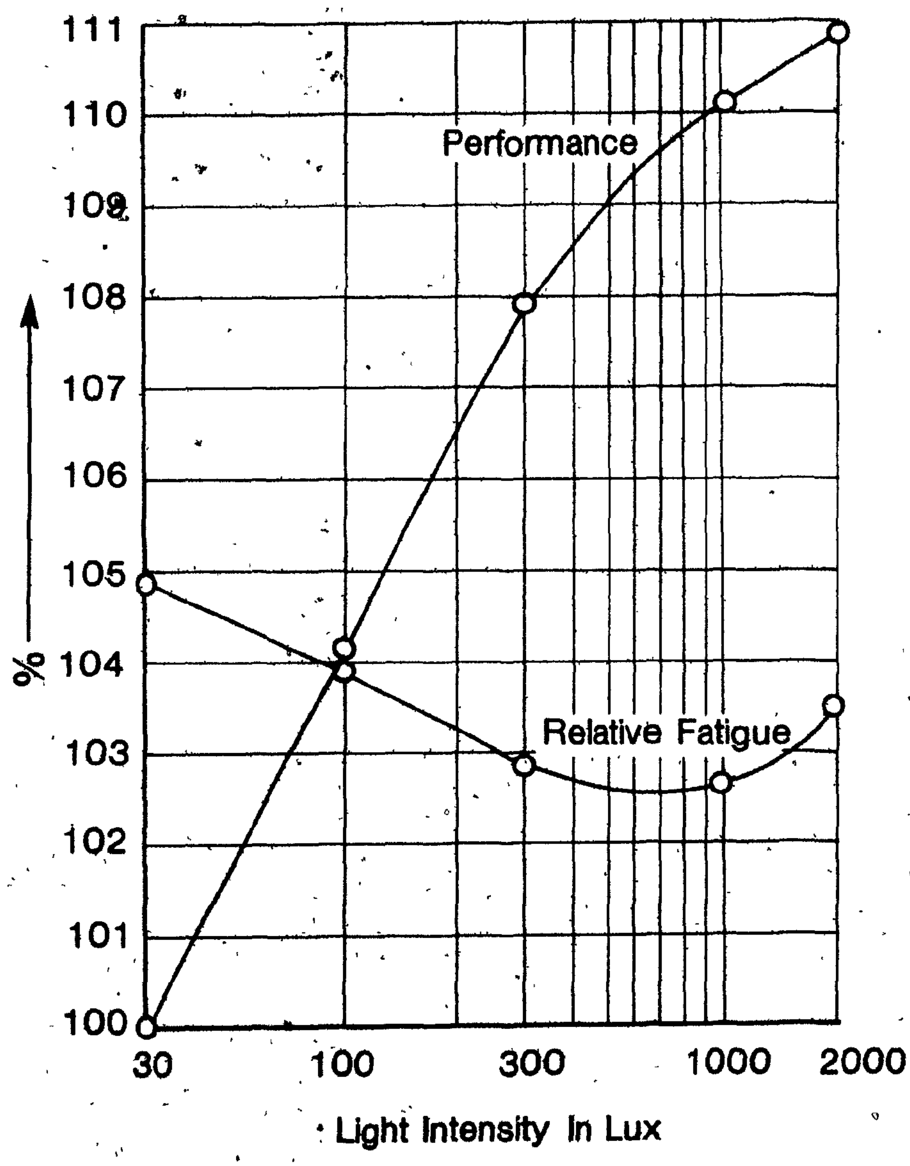
— Fatality Rates In Various Age Groups In British Coal Mines.

Figure 4

On surface, where visibility is better, this correlation does not exist. Figure 4 illustrates the point. While accidents to older men may be due in large part to lengthening reaction time and slower movements, better visibility would help counter this. The need for better underground lighting is inferred since an older worker may not be able to recover from a dangerous position in time to avoid an accident, but he might do so if he sees the danger sooner and is given more time to react.

A further indirect proof is provided by measuring, under carefully controlled laboratory conditions, the effects of light intensity on fatigue and performance. If a worker becomes fatigued or performs poorly because of low light intensity he becomes accident prone. Conversely, if increased illumination leads to faster visual perception and reduction in fatigue, greater safety should result. Figure 5 gives the results of an investigation by a German study group (62) studying these factors. With increased illumination, performance increased, and at 1000 lx fatigue, measured by a test of hearing threshold, was minimal. The number of errors also fell to a minimum at this level of illumination.

In any occupation, fatigue from visual stress results in production losses, lowered quality of work, increased frequency of errors, and an increase in the accident rate. In a report of the United States National Safety Council (1),



Effects Of Light Intensity On Performance And Fatigue

Figure 5

experts estimate that insufficient lighting was the sole cause of 5% of all industrial accidents, and that in 20% poor illumination and hence eye fatigue played a part. Percentages would be much higher for accidents in mines.

Lighting intensity related to accidents has been given more attention in Europe than it has on this continent. In Britain, Whitfield (68), Ragsdale (55), Parker et al (52) and Roberts (58) bear mention. In continental Europe, Beroundsky (16), Krivohlavy (44), Schaffer (62) and Halmos (38) have quantitatively related lighting intensity and accidents. Halmos refers to research into mine lighting in a Hungarian lignite mine. When one part of a mine was lighted with artificial lights and the other part illuminated only with cap lamps, the accident rate decreased by 60% in the lighted portion. Using a level of 20 lux as a statistical base in another study from the same report, Table 4 shows the correlation between the illumination level and the number of accidents.

TABLE 4

Illumination in Lux versus Number of Accidents

Illumination in Lux	Number of Accidents in %
20	100
200	68
250	58

A similar mine study has been undertaken on this continent in a large West Virginia coal mine (120). At this mine, the conventional room and pillar system of mining was carried out and conventional off-track equipment was used. Six production sections of this mine were in operation during the 24 month period during which the test was conducted. An experimental mine lighting system was installed in Section D. The major accident record for the six production sections is given in Table 5.

TABLE 5

24 Month Accident Record for Six Production Sections of a West Virginia Coal Mine

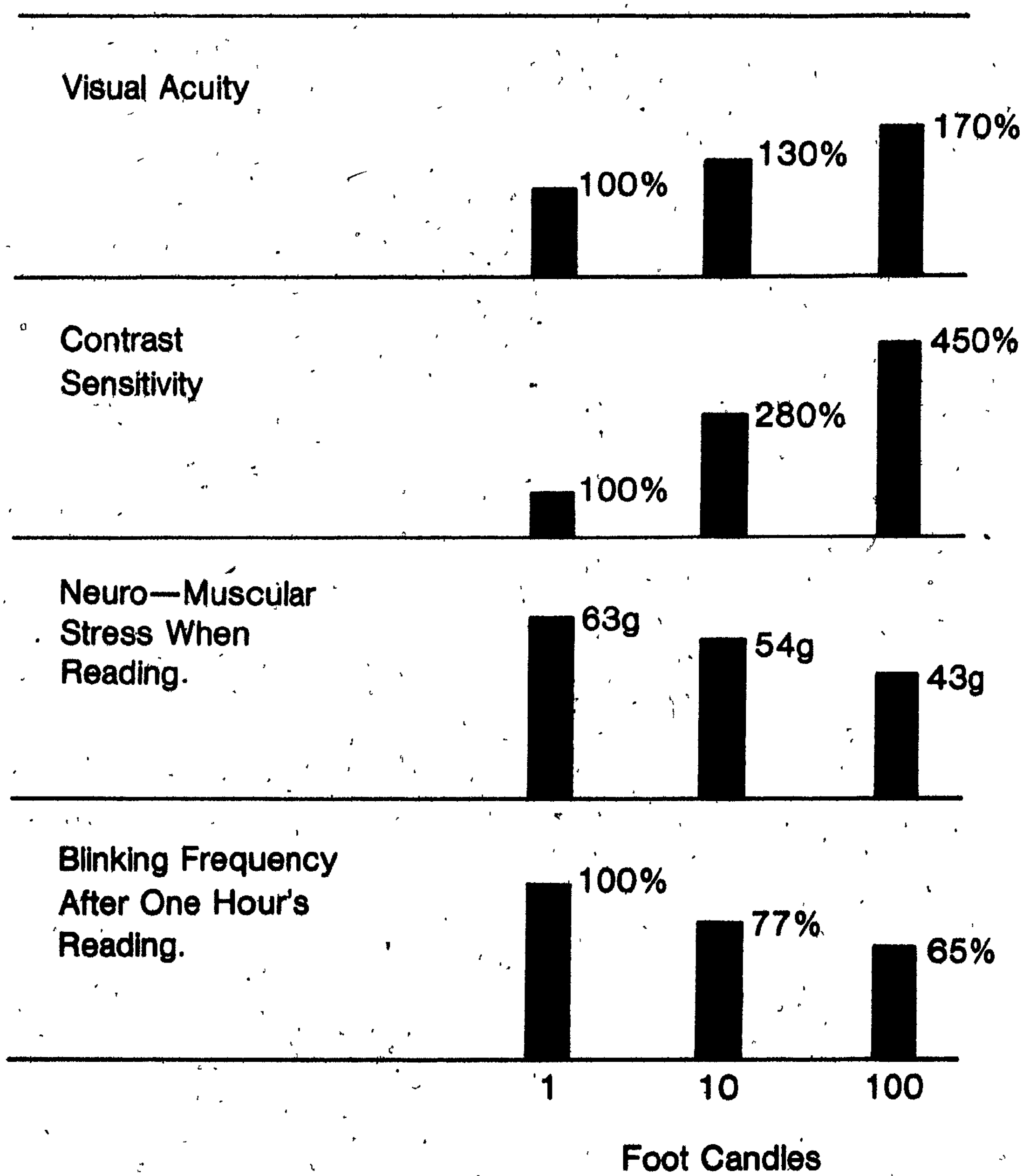
Section	Number of Accidents
A	1
B	1
C	2
D	0
E	1
M	5

Similar mine accident research reports based on lighting criteria are hard to come by. On this continent most studies concern themselves with the correlation between industrial accidents or road accidents and illumination. A study by General Electric showed an accident reduction of 32% when the illumination level was raised from 50 to 200 lux at an Allis Chalmers factory (1). A further decrease of 16.5% was achieved when the contrast was reduced, giving more even illumination. These figures should not be taken literally. The improvements could also mean safer working habits result because more attention is being paid to the worker.

Road accidents decrease with increasing illumination until a level is reached above which no further reduction is apparent (24). The avoidance of accidents would depend greatly on visual acuity, contrast sensitivity, and speed of perception all of which have a dependence on the level of luminance and on the difference in luminance between the object and its environment.

In practice an improvement in visual acuity is accompanied by an increase in contrast sensitivity and speed of perception. Figure 6 gives the results of laboratory experiments by Luckiesh(6). An increase in light intensity from 10 lx to 1000 lx produced an increase in visual acuity from 100% to 170% and in contrast sensitivity from 100% to 450%. At the same time a decrease in muscular stress, measured through the continuous pressure of a finger on a key, and of the blinking frequency was recorded. This was explained as a lessening of nervous stress with higher light intensity.

Enough evidence exists to show that lighting often is a factor in underground accidents. Accident record reporting forms at mines usually state name, location, witnesses, act



Effects Of Light Intensity On Visual Acuity, Nervous Stress And Contrast Sensitivity, Blinking Frequency. (Lukiesh And Moss)

Figure 6

being performed, equipment used, where and how hurt, and time of accident. These forms should also stipulate the method and condition of the lighting at the accident site, should specify whether lighting might have been a factor in the accident, and should record the actual illumination levels for severe accidents. Each mine should have suitably calibrated photometers as normal equipment so that measurements can be made. Safety engineers should be trained to make a lighting survey and become knowledgeable in the idiosyncracies of photometers. The writer knows of no Canadian mine where any of this is done. Yet a compilation of these records over a period of time could produce valuable information for the researcher and ultimately the designer of underground lighting installations.

4.3 Lighting and Production

It is easy to set up some simple task for workers to perform, such as threading needles, and measure the rate of work done by the same worker under different lighting conditions. Many examples of this type of carefully controlled laboratory experiment can be cited (1,36,43,46). In general, performance increases up to about 1000 lx. Increasing the illumination beyond this point does not seem justified in terms of the increased production which might be achieved. The economic cut-off point though depends on the nature of the task (14).

Similar experiments have been performed in factories and offices. To cite one example, an investigation was made of the effects of increasing the illumination in an American cotton mill (1). After increasing the intensity of light from 170 lx to 340 lx, production rose by 4.6%, and the number of rejects was reduced substantially. When production costs fell by 25%, management decided to increase the illumination to 750 lx. Production rose by 10.5% measured from the 170 lx base and production costs were lowered by nearly 40%. Many countries report similar results. A good body of knowledge is available to the architect and office and factory lighting is often carefully controlled to give optimum production.

The conditions encountered in underground mining bear little similarity to controlled laboratory experiments or the conditions encountered in an assembly plant. Nevertheless the few underground studies attempting to measure production as a function of lighting levels indicate a strong correlation. Two studies are worth citing.

Halmos (38) describes studies done in the Hungarian coal mining industry. In one mine, one part of the working area was illuminated with general lighting while the other part was lighted by means of cap lamps. Over a 2 month period, production was up 5% per man when general lighting was used. A similar experiment in a different mine showed a 26% increase in production per man in the generally lit area over a 3 month period. The author points out though that conditions were not identical in the two working areas being compared. Since the study was done in 1962 it is probable that the cap lamps being used were carbide lamps as Hungary was relatively slow in converting to tungsten filament lamps. An interesting report was made on this continent (131). One section of a large mine was selected for the test and was equipped with general lighting. Over a one year period production measured in t/man shift was 17% above that of the next highest producing section.

To date research in this area has been mostly confined to coal mining. Visits by the writer to several Canadian metal mines show that there is a definite trend towards installing general stope lighting. The companies involved may well be in a position to measure production rates over a long period of time both before the lighting was installed and after it was installed. Several companies keep records on accidents to equipment. A comparison of equipment accident rates before and after increasing the lighting level would be interesting.

Articles in mining journals exploring these themes should be forthcoming. These articles could act not only as an incentive to other operators to install permanent lighting in the working place but would also aid the mine lighting designer to provide the optimum quantity and quality of light. If mine lighting is to be vastly improved, it will either be done because government legislation decrees that certain standards be met or because the mining industry does it voluntarily. It will be done voluntarily if the benefits which accrue either in terms of increased production per man shift, lower repair cost to equipment, or lower workmen's compensation rates, can be proven.

CHAPTER 5

INSTRUMENTS FOR UNDERGROUND ILLUMINATION AND LUMINANCE SURVEYS

5.1 General

The unaided eye is a poor judge of luminous intensity. To measure illumination and luminance levels some form of light measuring instrument must be employed.

Three completely different measuring methods have been used for underground lighting surveys. These are:

1) Physical Photometry

2) Photographic Photometry

3) Visual Photometry

With the first method, a device such as a photocell is used to record the light level. The second method uses a camera to record the illumination level. In the third technique the eye is the judge of the luminous intensity using a light matching method.

5.2 Physical Photometry

Direct measurements of illumination can be obtained by using a photo-electric cell. The cell commonly employed is a selenium barrier layer cell and the instrument may consist only of the cell and a sensitive micro-ammeter. When the cell is exposed to light, electrons are emitted and the current produced is proportional to the light energy absorbed. These are available with very high sensitivity in terms of instrument deflection per lux, a necessary condition for underground surveys. Since it has to be portable and rugged when used underground, either a large cell or a bank of cells coupled in parallel is used to get the required output in dim light. This simplicity and independence of any external source of power make them popular for underground illumination surveys.

The output of the cells can also be measured by instruments employing the current balance (null balance) principle. With this system, incident radiant energy proportional to the value of resistance required to reduce the voltage across the cell or combination of cells to zero, is used.

Other physical photometry devices are available. Photoemissive tubes require more complicated measuring circuits than barrier-layer cells but have desirable characteristics for the measurement of light. Photoresistive elements and thermopiles have specialized applications. Sensitive current or potential measuring instruments or bridge circuits are used with them (83).

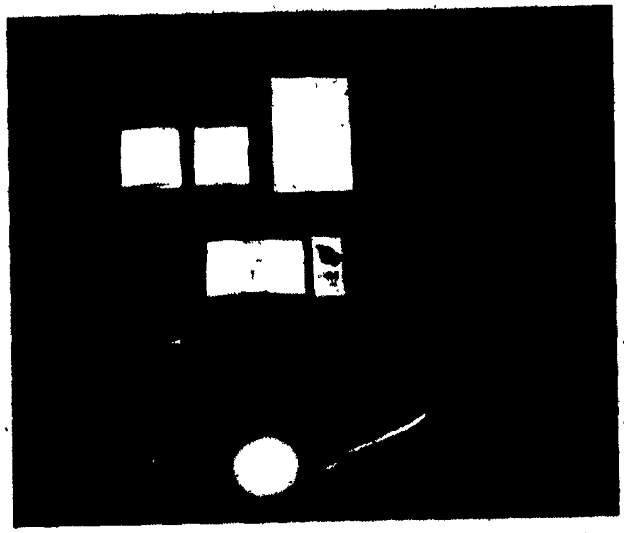
Instruments may be single range or multi-range. The multi-range instrument has the advantage of lower cost than individual instruments to cover all the ranges, but has disadvantages as well. In general, it is good practice to use single range instruments for routine testing and multi-range instruments for special tests, particularly in the field.

5.2.1 The "EEL" Lightmaster Photometer This photometer was used in the present study to obtain general levels of illumination in underground working places. It has three ranges of sensitivity with scale selection obtained by using a rotary switch. In the off position the instrument is short circuited and the meter coil is damped to prevent swinging.

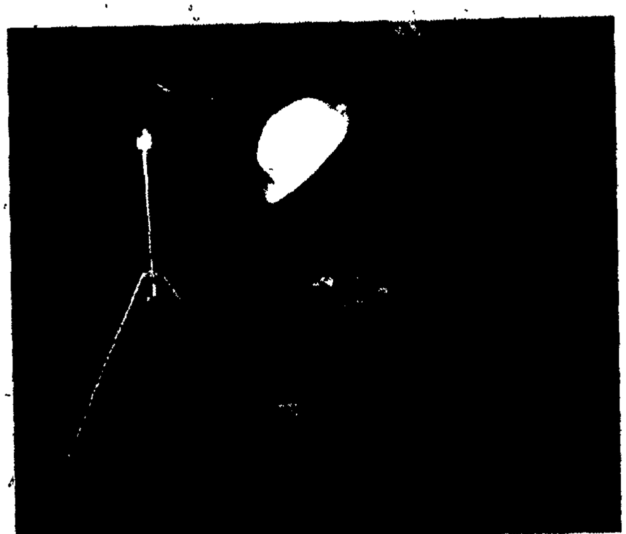
The instrument is supplied with two measuring heads so that it can measure light intensity as well as colour temperature. Both heads plug into sockets in the handle which is connected to the meter. The photometer head is a mounted, barrier-layer cell, while the colour temperature head has a semi-circular shutter for sensitivity adjustment, and a rotating filter. Figure 7 is a photograph of the instrument (87).

Light intensity was measured with the photometer head. The least sensitive scale was switched in first, and then a more convenient range was selected if necessary. Where possible, readings were taken at the right-hand side of the dial rather than the left-hand side. Figure 8 illustrates the field use of the instrument.

By means of the tripod arrangement and special mounting bracket the working plane of measurement was established at a fixed height. The operator then read the meter placed on the floor. By staying in a stooped position to take the reading, the operator does not cut off any light which otherwise would strike the photometer head. Correction factors have to be applied to the raw readings.



EEL Lightmaster Photometer
Figure 7



Field Use of EEL Photometer
Figure 8

5.3 Photographic Photometry

This method has been used to measure luminance and its distribution. It is based on the theory that the amount of blackening of a negative is proportional to the luminance of the photographed object. Luminance analysis can be done by regulating the conditions of exposure and development and by providing a system of measuring and calibrating the blackness of the image (7,13,59).

Several advantages become apparent. The negative can be stored for the extraction of additional information at a later date. Any level of luminance can be measured by varying the camera settings. Measurements can be made in the laboratory which enable greater care and accuracy than is possible underground. The whole visual scene is recorded so that measurements of contrast, disability glare, and perspective which are necessary for task evaluation and usually require several measurements, can be made off the one photograph. One particular use which has been studied is the determination of a disability glare index system using the luminance distribution to yield a value of adaptation luminance for any given visual field.

The technique has not proven very popular in spite of these inherent advantages. Great care is required in the selection of the camera, lenses, accessories and film. Suitable filters have to be used to correlate the spectral response of the photograph to that of the eye. Since the development of a photographic film is dependent on a great number of variables, great care in developing is necessary. A technique of image blackness measurement so that the degree of blackness may be related quantitatively to luminance by a photographed luminance scale must also be established. Inherent errors in the method are covered in Section 6.6. For these reasons the method was not used in this study.

5.4 Visual Photometry

A visual photometer operates by visual comparison of brightness by determining the brightness of a test plate and using this known brightness to calculate the illumination or luminance of the area being measured. A standard test plate of known reflectivity is placed at that point where the illumination or luminance is to be measured and the brightness of this plate is assessed. The illumination or luminance at that point is then calculated by dividing the brightness figure obtained by the reflectivity of the standard test plate surface. This procedure is followed at every point where measurements are to be made. Each different instrument depends on this same basic principle; namely that the brightness of the field of view is compared to that of a small surface illuminated under standard conditions.

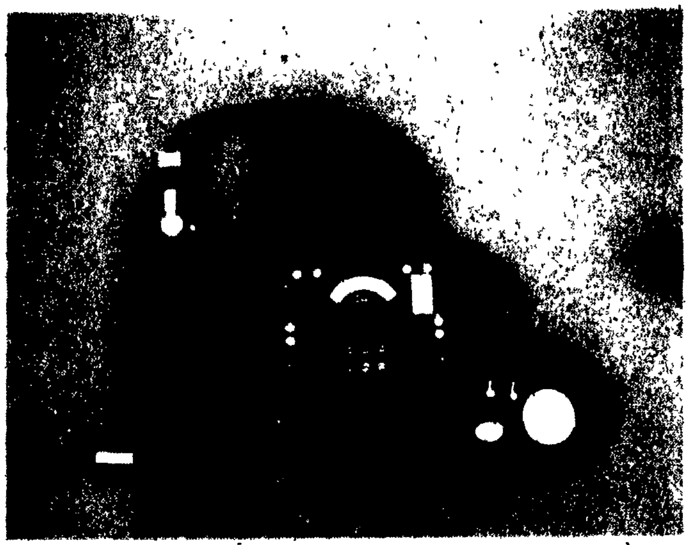
Instruments consist of an internal standard lamp which illuminates the comparison field whose brightness can be controlled, and an optical system which allows the comparison field to be viewed at the same time as the object which is to be measured. A determination consists of viewing the object through the optical system and then altering the brightness of the comparison field until both object and field appear to be at the same brightness level.

Two types of visual photometers were used in this study. These were:

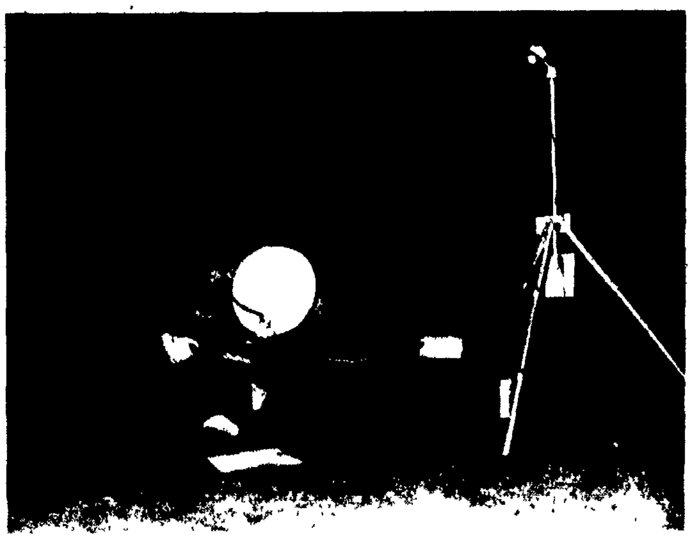
1) the MacBeth Illuminometer (89)

2) the S.E.I. Photometer (91)

5.4.1. The MacBeth Illuminometer This instrument was used for reflectivity measurements both in the field and in the laboratory. Referring to Figure 9, from left to right are (1) the illuminometer, (2) the controller, (3) the reference standard, and (4) the test-plate. Figure 10 shows an early field use of the MacBeth Illuminometer in an underground mine. The reflectivity of sand fill in a cut-and-fill stope is being measured. The observer is sighting through the illuminometer eye piece onto a test-card to determine the luminance emanating from the card. The controller is shown on top of the carrying case and a battery operated fluorescent lamp to read the controller dials is immediately to the right of the controller. A light source matching the illuminometer light is mounted on the top of the tripod. To check for battery decay, a meter is attached to the tripod.



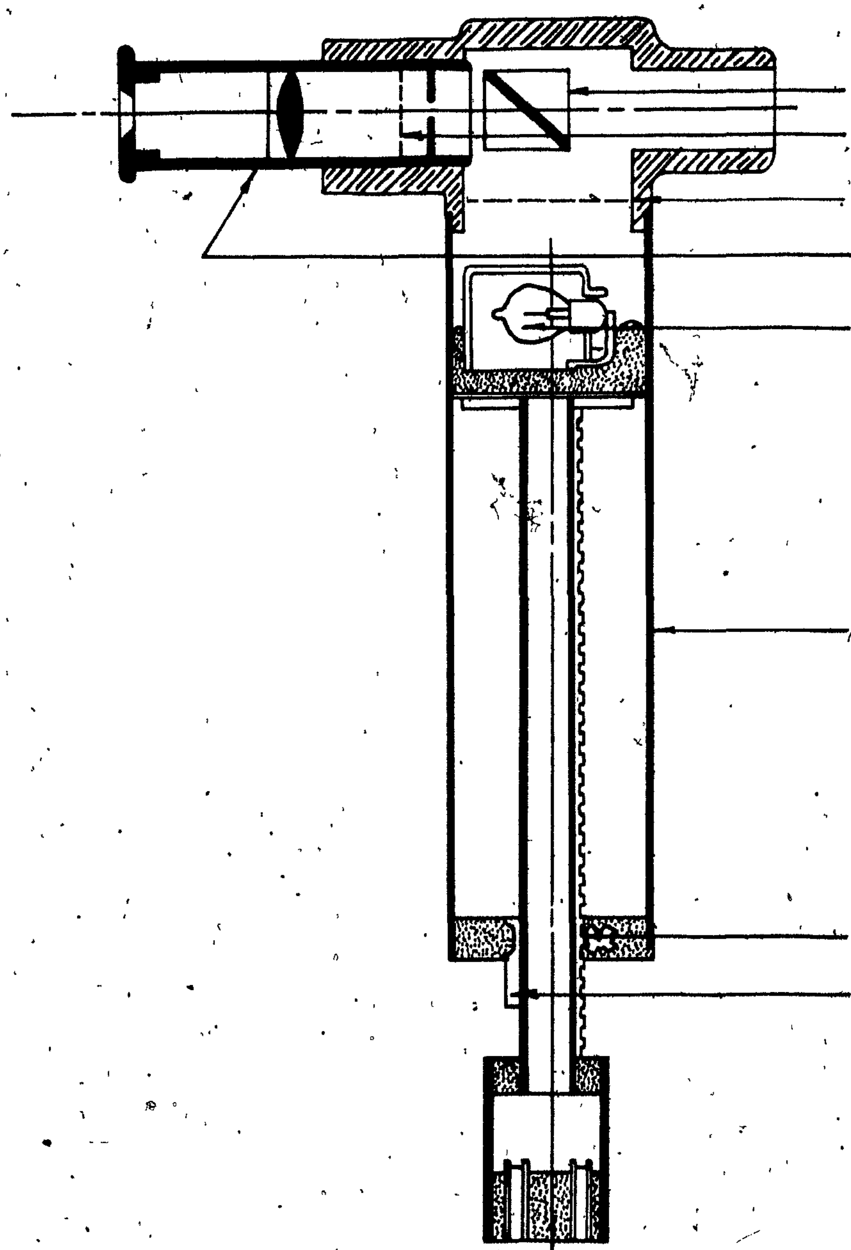
The MacBeth Illuminometer
Figure 9



Field Use of MacBeth Illuminometer
Figure 10

1) Illuminometer Figure 11 shows a cross-section of the illuminometer. The operator sights through the telescope and points the open end to the surface to be measured. A concentric circle type Lummer-Brodhun cube is mounted in the rectangular head. The inner circle is illuminated by light from the surface being measured while the outer circle is illuminated by the working standard. The working standard used in this study was a 3 volt 1/4 amp G.E. #512 incandescent lamp.

Measurements are made by the balance principle. Photometric balance is obtained when the brightness of the centre circle equals the brightness of the outer ring when viewed through the eyepiece. The tube contains a rack and pinion arrangement for moving the carriage which supports the working standard. The measured quantity of luminance is read from a calibrated scale on the rack at an index point. This scale gives direct readings in the range of 10 to 250 asb but the range can be extended by using two neutral absorbing screens to cover readings between 0.1 and 25000 asb. The screens are inserted either in position 1 or position 2 depending on whether the unknown illumination is higher than the working standard or lower than the working standard. Both screens are numbered to facilitate identification and were calibrated by the Physics Division of the National Research Council in Ottawa. Calibrations are given in N.R.C. Report PO-53 (97), and N.R.C. Report PO-90 (108).



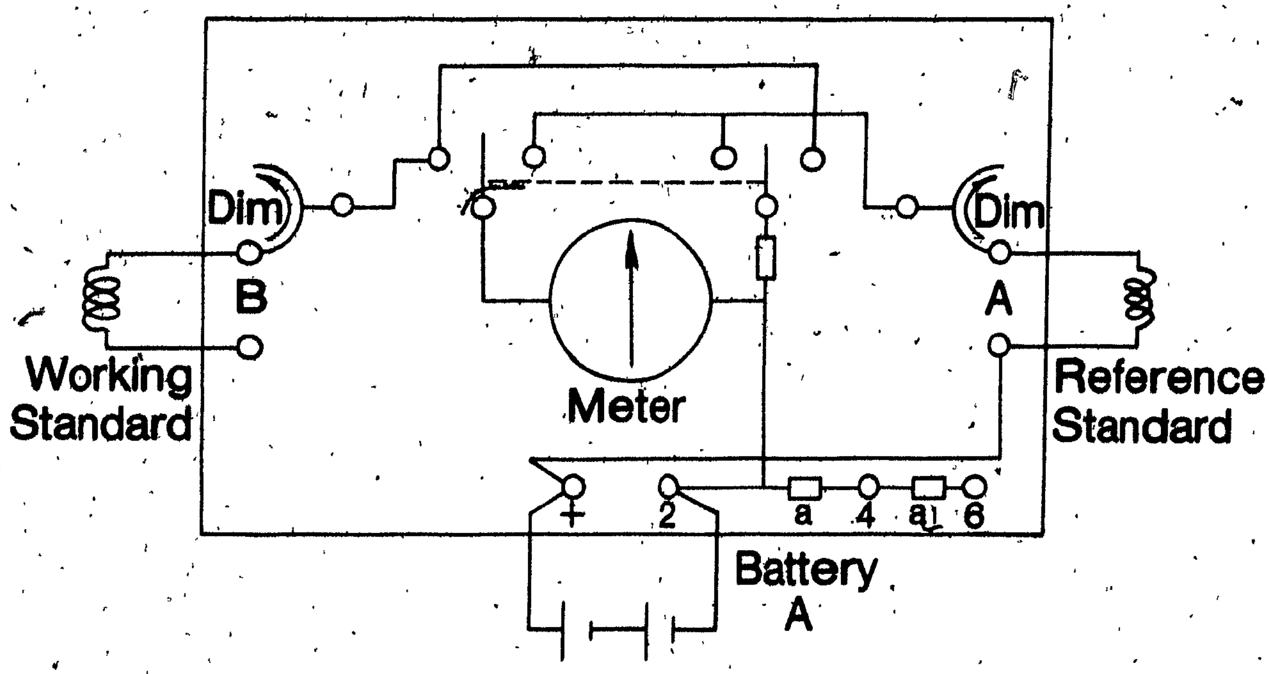
MacBeth Illuminometer Cross-Section

Figure 11

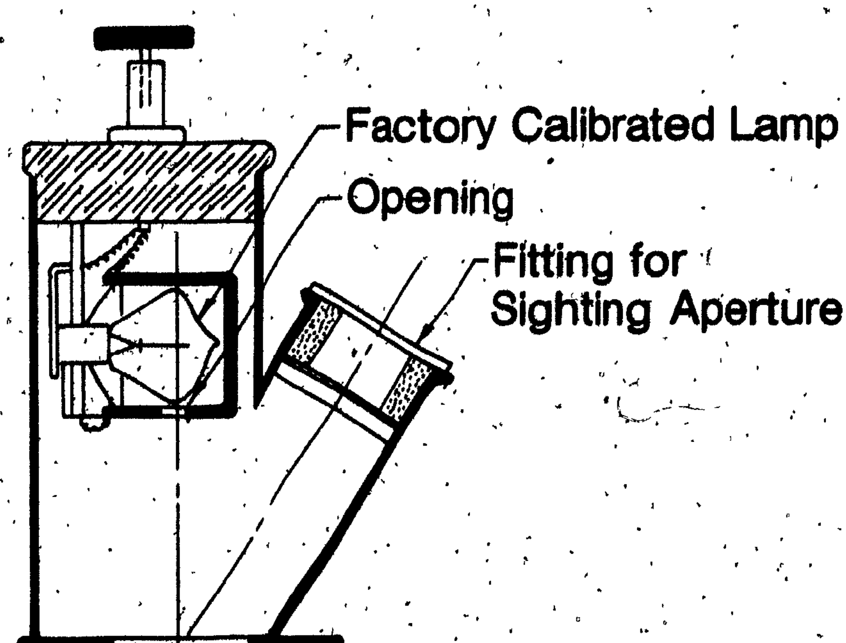
2) Controller: A battery powered controller supplies electrical energy for the lamps in the illuminometer and reference standard. A wiring schematic of the controller circuit is given in Figure 12. Rheostat A, in series with battery A, controls current flow through the reference standard lamp while rheostat B and its battery control the working standard lamp. The double-throw switch is used to shift the milliammeter from one lamp circuit to the other. For field use two No. 6 dry cells were connected in series and installed in a leather pocket under the controller. For laboratory use three dry cells were used.

In order to permit full insertion of the terminal pins on the cords which connect the controller to the illuminometer and reference standard lamp it is necessary to turn both rheostat knobs on the controller face plate in the direction of the arrow marked DIM as far as they will go. This safety feature places maximum initial resistance in the circuit to avoid damage to the working and reference standard lamps.

3) Reference Standard: Illuminometer accuracy is checked by using the reference standard. Figure 13 shows a cross-sectional view. Lamp A, identical to the working standard lamp, was initially factory calibrated to develop a light of accurate, known intensity when a specified current energized its filament. This current was listed on the reference standard certificate obtained from the manufacturer and is included in the instrument report (118). The lamp was



Controller Circuit
Figure 12



Reference Standard
Figure 13

further calibrated from time to time as use warranted.

During a check the reference standard is placed upon the test plate, illuminating it by means of the lamp through the opening below the lamp. The illuminometer is calibrated by placing its sighting aperture into the hole, setting its scale to the value given in the latest reference standard certificate, and adjusting the current through the working standard until a balance is observed at the Lummer-Brodhun cube. When the reference standard is not in use, the opening is protected by its pivoted cover plate.

4) <u>Test Plate</u>: The test plate is used in the calibration of the working standard. The surface of the test plate material should be a Lambert surface but in practise this surface is impossible to obtain. By making the plates of glass finished by a special process, the surface shows practically no error for angles of incidence between 0 and 25 degrees. For these angles the reflectivity of the test plate is 0.79 provided the viewing angle is kept on the opposite side, under 25 degrees, and in the same plane (79). Figure 14 shows the error for various angles of incidence and compares this surface to other common surfaces.

<u>Calibration</u>: Each time a series of illuminometer readings are to be made, the working standard lamp must be recalibrated. Referring to Figure 12, the reference standard is connected to binding posts A and the illuminometer to binding posts B. The double-throw switch on the controller is snapped to position B and kept in that position for a few

Test Plate Curves

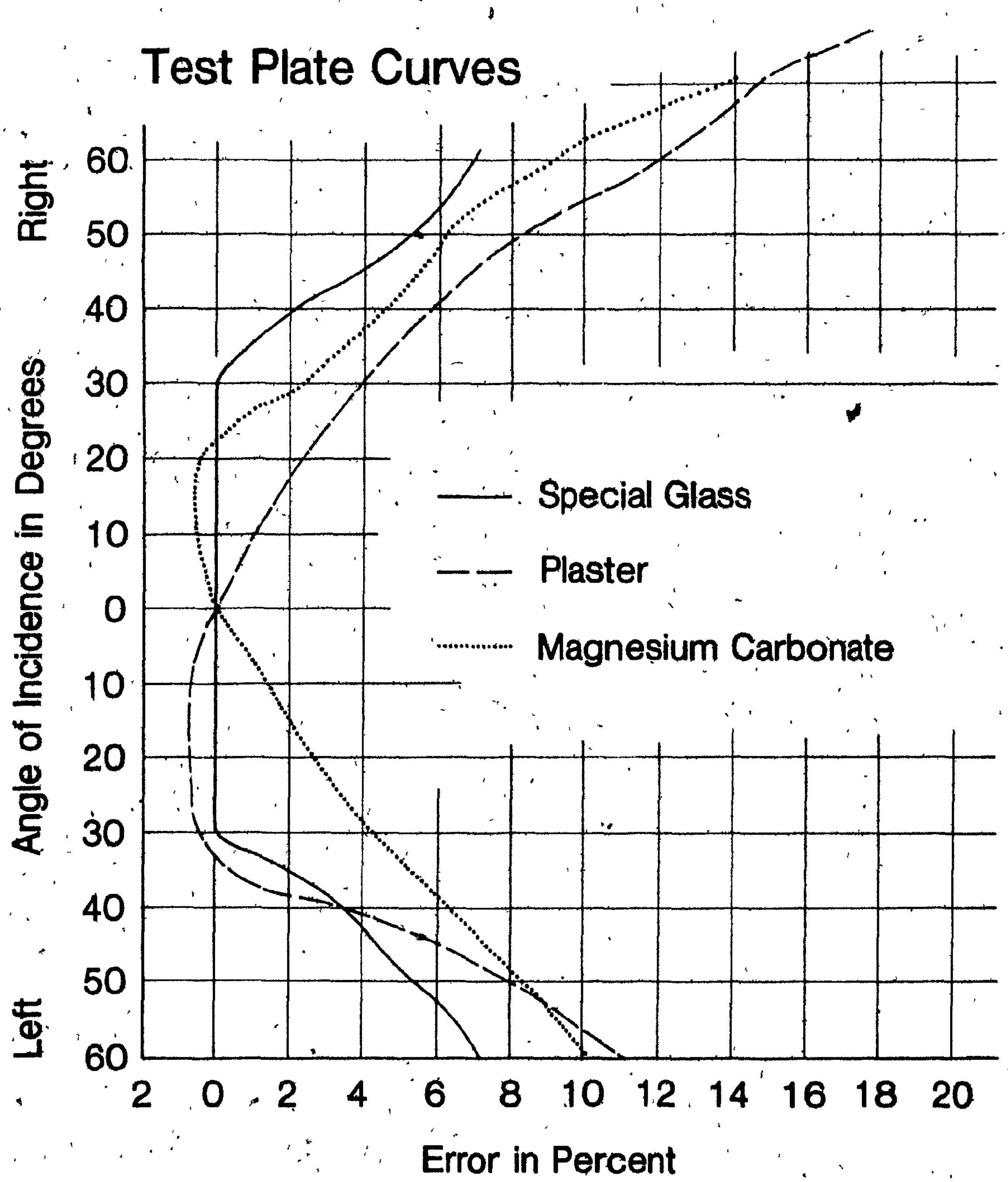


Figure 14

minutes so that the battery voltage and current may have time to stabilize. With the reference standard on the test plate the switch is snapped to position A. Rheostat A is turned in the direction opposite to that indicated by the arrow until the milliammeter reading corresponds to the current value listed in the reference standard certificate.

The illuminometer scale is set to 32.28 lux which is the value listed in the reference standard certificate. With the switch snapped to position B, the sighting aperture of the illuminometer is placed in the hole of the reference standard. The current is adjusted through the working standard by turning rheostat B until an optical balance is secured, meaning that the outer circle matches the inner circle in brightness. When a balance is obtained, the milliameter scale is read to obtain the value of the current flowing through the working standard. Since the colour temperature of the working standard lamp is the same as the colour temperature of the reference standard lamp, about 2360 K, optical balance is easily obtained. This is repeated several times to make sure the same milliameter value is obtained each time. This value is noted for future use. The switch is snapped to position A again to make sure the value of the current flowing through the reference standard has not changed. If the reference-standard current has changed, the batteries have to be replaced and the calibration procedure repeated.

The working-standard current must be maintained throughout all subsequent measurements at the value established and noted during calibration. With the switch in position B the current is adjusted with rheostat B whenever a change in the working-standard current occurs. The reference standard is disconnected as soon as the working standard has been calibrated. In Figure 15 the operator is adjusting the current to obtain a luminance balance between the working standard lamp and the reference standand lamp.

Measurements are made to determine reflectivity of various mine surfaces with the illuminometer either handheld or tripod mounted. Since the diameter of the field of observation is roughly one-tenth the distance between the observer and the surface being observed, care must be taken so that the observer is close enough to make the object being viewed appear completely on the inner field of the Lummer-Brodhun cube. The angle between the axis of the telescope and an axis vertical to the test plate as well as the angle between the axis vertical to the test plate and the light source should be recorded. These angles are called the record angle and the incident angle respectively. On structured surfaces the angle between the plane of the surface being measured and the plane formed by the incident beam and the recording line of sight are also measured. This angle is called the tilt angle. Figure 16 illustrates how the incident angle is predetermined for a reading on

Field Calibration of
Macbeth Illuminometer
Figure 15

Setting up for 45°
Incident Angle
Figure 16

Measuring Tilt Angle
Figure 17

sand fill in a cut-and-fill stope and Figure 17 shows how the tilt angle is measured.

As noted previously, two concentric fields are seen through the eyepiece. If the surface under observation is exactly the same colour as the light from the working standard, the line of demarkation will disappear when a balance is obtained. If there is a colour difference it will be impossible to obtain this disappearance and the user has to judge when the two fields are of equal brightness. Whenever reflectivity was measured in other than diffuse light a modified cap lamp was used as the light source. This cap lamp was equipped with a bulb identical to the working standard bulb and constant illumination was obtained by metering the current through the controller. In this manner, errors due to colour difference and battery decay were eliminated.

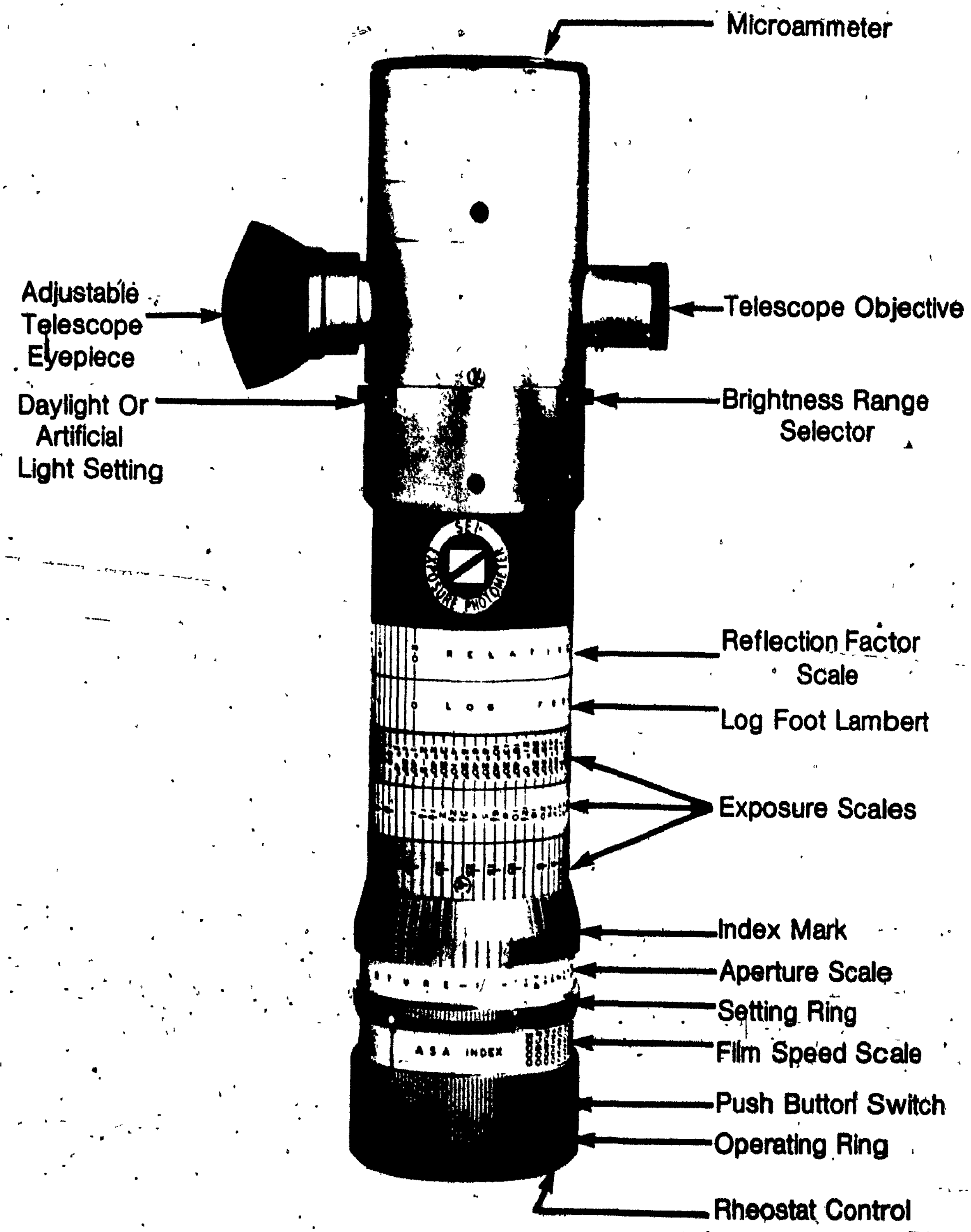
After balance has been obtained, the measured value is recorded on an appropriate form. Table 20, Appendix G, illustrates a typical completed form with one set of observations. As a general rule, several separate readings are made for each observation (47). After each reading the working standard current must be corrected for by means of the rheostat dial, the illuminometer scale is ratcheted up or down, and a new balance is obtained and recorded.

Once a series of observations have been completed it is necessary to recalibrate the illuminometer. This is done by repeating the calibration procedure once again.

Only if the same working standard current is arrived at can the series of observations be accepted as valid. Then appropriate calculations are performed on the raw data (47). These calculations take into account the root-mean square of the various readings, the reflectivity of the test-plate with which the standardization was made, the reflectivity of the test card, the angle of incidence and the recording angle, and any filter factors if filters were used. In this manner both the brightness and the reflectivity of the surface being tested can be obtained. It is then possible to group several sets of data and treat them statistically in order to arrive at a mean value and a standard deviation about the mean. Results can then be presented in concise table form (Appendix G).

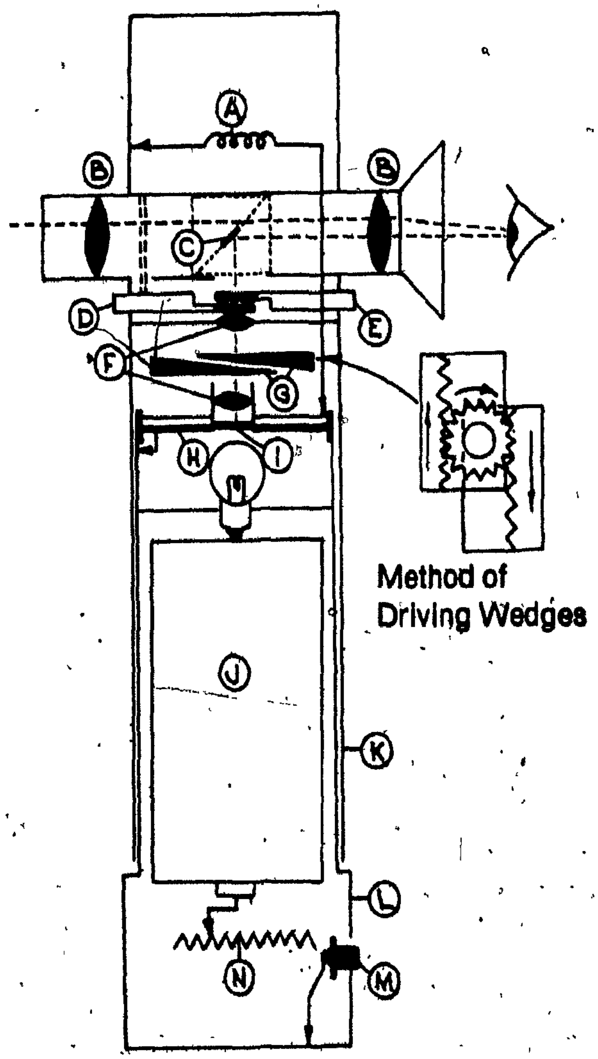
5.4.2. The S.E.I. Photometer This is a portable photometer manufactured by Salford Electrical Instruments Limited. Figure 18 is a photograph of the instrument while Figure 19 is a schematic diagram.

Referring to Figure 19, the subject is viewed approximately full size but inverted, through a simple telescope (B). By an adaptation of the Lummer-Brodhun cube, a small comparison spot (C) is superimposed on the centre of the image field, this spot subtending at the eye an angle of only ½°. The spot is diffusely illuminated by a small electric lamp via a diffusing screen (I), the



S.E.I. Photometer

Figure 18



SCHEMATIC DIAGRAM

A	Microammeter Coil	H	Photo Cell
B	Telescope Lenses	I	Diffusing Screen
C	Mirror 'Spot'	J	Dry Cell
D	Range Shift Disc	K	Brightness Scales
E	Colour Match Disc	L	Film Scales
F	Collecting Lenses	M	Lamp Switch
G	Optical Wedges	N	Rheostat

The S.E.I. Photometer

Figure 19

lamp being fed by a dry battery (J) through a rheostat (N). The lamp also illuminates a ring-shaped photo-cell (H) which is connected to a microammeter (A). By adjusting the rheostat, the pointer of the microammeter is made to coincide with a standardizing mark so that the luminous output of the lamp and consequently the brightness of the "internal reference surface" (I), are always at a constant value. The instrument is therefore self-standardizing.

Situated between the lamp and the spot are two opposed photometric wedges (G). These are moved in opposition to one another by a rack and pinion mechanism operated by rotating the base (L) of the photometer. The light reaching the comparison spot can in this way be varied through an intensity range of 100 to 1. Reduction of the brightness of the subject or spot by the insertion of neutral filters attached to a range shift disc (D) provides a further increase of range up or down by factors of 100 thus giving the instrument a total range of 10^6 to 1. The range shift disc has three index marks. For underground measurements the red mark is kept central under the object lens of the telescope. At this mark the meter is set for measurements of low brightness. Measurements are made on a logarithmetic scale.

To make easy the comparison of brightness between spot and object a colour correcting filter is provided in disc (E) situated immediately below the telescope eye-piece. The calibration of the instrument is unaffected by the movement of the disc. The photometric setting can then be made causing the brightness of the spot to match that of the scene.

The instrument possesses two advantages over most photometers. It can be used to measure the brightness of very small areas in the scene since the spot in the field of view subtends only an angle of $\frac{1}{2}^{o}$, and the range of brightness which may be measured accomodates low values found in general underground illumination studies. The instrument was particularly useful then in obtaining reflectivity measurements of small areas such as drill-steel and in obtaining contrast measurements between two small adjacent patches of light.

CHAPTER 6

ERRORS IN MEASUREMENT

6.1 General

Anyone involved in taking lighting measurements should know how meaningful his readings are, particularly since there are many factors which rob us of the ability to define a measurement exactly. It is very easy to have a divergence of 15 or 20 per cent or more from the true value and, unless one is aware of the factors causing divergence, completely spurious results can unwittingly be reported (40,41,63). Because of the importance of error in lighting measurement, the topic has been alloted a separate chapter.

A brief outline of the more pertinent ideas in error theory is followed by specific descriptions of errors involving physical photometry, photographic photometry, and visual photometry.

6.2 Types of Error

Four types of error are recognized, depending on the cause. These are:

(1) accidental error

(2) systematic error

(3) short-term error

(4) constant error

6.2.1 Accidental Error These errors are not constant and are as likely to be above the true value as below it. They can best be handled by taking several readings and using the root mean square method to give a weighted value to the group of readings. This weighted value is obtained by squaring each value, obtaining the sum of the squares, dividing this by the number of readings, and then taking the square root. Readings taken with the MacBeth Illuminometer were handled using this method. There is, however, a practical cut-off point as to how many readings to take. If one doubles the number of readings of a single quantity, one can expect to improve the results by the square root of two. The principal is illustrated in Table 20, page 209, where seven observations on the test plate were taken.

Accidental errors include the human errors of observation and, for lack of a better place in which to group them, the mistakes in calculating or in recording. In this study, independent calculations by two experimenters* employing different calculating methods and the repeating of all recorded values between the observer and the recorder, ensures the virtual elimination of accidental mistakes.

6.2.2 Systematic Error A series of observations that shows any pattern or trend, other than that of grouping around the standard deviation curve, is a good indication of a systematic error. A systematic error would cause readings to be either consistently above the true value or consistently below the true value. A systematic error was recognized when using one of the filters for the MacBeth Illuminometer and recalibration by a standard laboratory resulted in adopting a different filter factor from that provided by the manufacturer. Generally for this type of error when enough data has been accumulated a table of corrections can be worked out and correction factors can be applied to future readings.

6.2.3 Short Term Error The short term in this expression refers to a short duration in time. If reading off a dial, a vibration might introduce an error. Since the error is not likely to reoccur when repeating the measurement, the error can be recognized. Short term errors were handled by discarding any reading which obviously varied greatly from the mean of a series of observations.

6.2.4 Constant Error These have the same effect on all readings in a series. A photometer may be calibrated for a particular type of light source. Changing the light source would introduce a constant error. Constant errors for the EEL Lightmaster were provided by the manufacturer, so that it is a simple matter to apply corrections.

6.3 Probable Error

The probable error of a series of observations is defined as that mean error for which there are as many larger errors as there are smaller errors. Formulae have been derived which show that, for much of the work under discussion, the probable error can be found by multiplying the standard deviation by the constant factor 0.6745.

The standard deviation is a measure of the spread of the readings contributing to the mean value. Standard deviation is the square root of the sum of the squares of the departure about the arithmetic mean of all the readings in the group. Plus or minus one standard deviation about the mean includes 68% of the readings taken. Two standard deviations about the mean include 95% of all the readings and three standard deviations about the mean includes 99.7% of all readings.

6.4 Accuracy and Precision

Accuracy refers to the closeness to the true value. For photometric measurements it is less than that of most other sciences for several reasons. A large part of this problem results from the fact that the basis of evaluation of subjective sensations may vary between individuals and the same individual at different times. Precision or reproducibility depends upon the equipment used and the skill of the operator.

Instruments are available in a wide range of prices and there is a rough relation between cost and accuracy. Table 6 is taken from Wiebel (65). Without adequate instrument accuracy, results are meaningless. At the same time unnecessary accuracy is expensive and difficult to justify.

TABLE 6

Accuracy Versus Cost for Photometers

Guaranteed Accuracy Per cent	Relative Cost Per cent
2.0	100
1.0	250
0.5	500
0.25	1000
0.1	4000

6.5 Physical Photometry Errors

Several possible sources of error may affect the results obtained by measuring with a physical photometer so that, if care is not exercised, entirely fictitious results may be obtained. These are:

(1) errors due to the differences between the colour response curve of the cell and the standard visibility curve.

(2) errors due to variation from the inverse square law.

(3) cosine errors.

(4) errors due to non-linearity of scale deflections.

(5) errors caused by normal wear.

(6) errors resulting from ambient conditions.

(7) errors in technique.

<u>6.5.1 Cell Calibration Error</u> Cell calibration is made by comparison with a standard light source operating at a definite colour temperature. Since the sensitivity of the cell is not constant for different wavelengths the calibration will not measure correctly a radiation at a different colour temperature. If true results are to be obtained the response of the cell to light should be similar to that of the eye. The typical photocell has a light response which is close to the human eye for yellow or green light but is more sensitive than the eye to red and violet and is still sensitive in the infra-red and ultra-violet range. No uncorrected physical photometer is available which has a spectral response equivalent to the human eye (45).

Corrections for this error may be made by applying colour temperature correction factors or using correcting filters. Readings should then conform with the visibility curve of the average eye. Unfortunately, some of the incident light is reflected by the filter so that it never reaches the sensitive cell surface.

The spectral response of each individual cell is different, even for those produced in the same batch. Consequently no one filter will correct all cells to average eye response. Cell-filter combinations are adequate for most work. However, when a cell is calibrated with light from a tungsten filament standard lamp and then used to measure fluorescent lighting, the error may be as high as 13%.

The EEL photometer used in this study to measure illumination levels was calibrated under strictly controlled conditions by the manufacturer using a tungsten filament at a colour temperature of 2700 K (87). Additional results on the effect of colour temperature were obtained by calibration at NRC in Ottawa (108). When sources other than tungsten filament were used appropriate correction factors supplied by the manufacturer were applied. Table 7 illustrates some correction factors for various sources both with and without correcting filters.

Table 7

Correction Factors - EEL Lightmaster

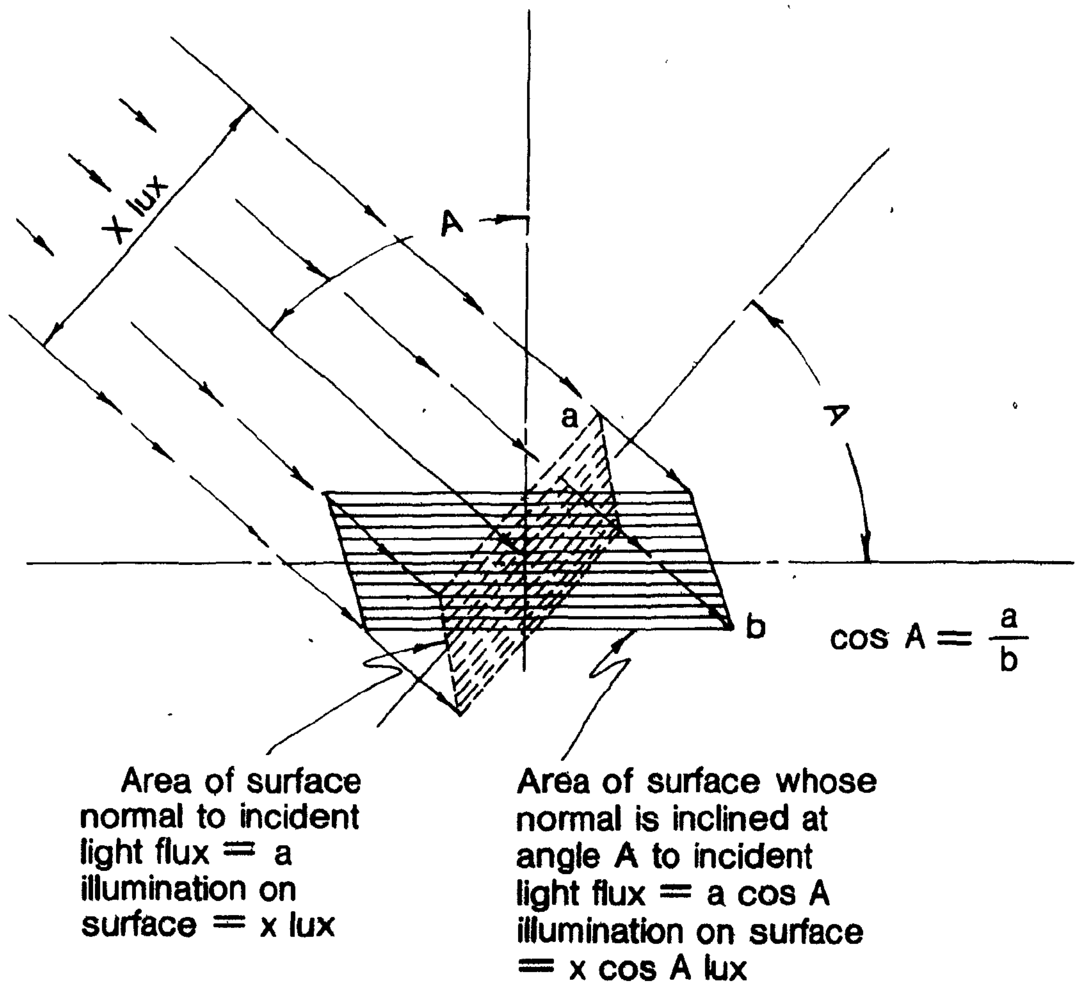
Source	Scale	Photometer Reading (lm/ft^2)	Eye Correction Factor	
			Without Filter	With Filter
2854 K	1	90.0	1.03	-
2854 K	2	96.7	0.960	-
2854 K	2	23.0	1.01	-
2854 K	2	9.00	1.01	-
2854 K	3	10.0	0.906	-
2360 K	3	5.61	0.923	-
2360 K	3	3.23	0.929	-
2360 K	3	1.05	0.971	-
Sodium	-	-	1.37	1.04
HP Mercury	-	-	0.87	1.21
HP Mercury (repeat)	-	-	0.907	1.00
Fluorescent (warm light)	-	-	1.14	1.14
Fluorescent (daylight)	-	-	1.03	1.11

6.5.2 Inverse Square Law Error This law is true only for a point source of light. Consequently using the law with lights of large surface area introduces error.

To keep the possible error to under 1%, the distance from the photocell to the light source must be greater than five times the source diameter. Roberts (7) suggests no measurements should be made with the photometer nearer to the source than ten times the maximum width of the lamp.

6.5.3 Cosine Error The illumination of a surface is proportional to the cosine of the angle of incidence of the light rays to that surface. This is known as the cosine law of illumination and is illustrated in Figure 20. If a given quantity of light strikes a surface at right angles, the illumination can be called X lux. If, however, the same quantity of light is incident at an angle A to the normal, then the illumination becomes X cos A lux. This arises because the surface is illuminated by an inclined cross section of the beam, the inclined cross section b having a greater area than the normal cross section a such that a/b = cos A. Since the luminous flux in the beam does not change, the degree of concentration of flux over b will be less than that over a and the illumination on the surface will be correspondingly less.

In planar measurement where a photocell is placed on the surface where the illumination is to be measured, the reading obtained is assumed to be the illumination on the surface under the photocell. The cosine law is ignored.



The Cosine Law of Illumination

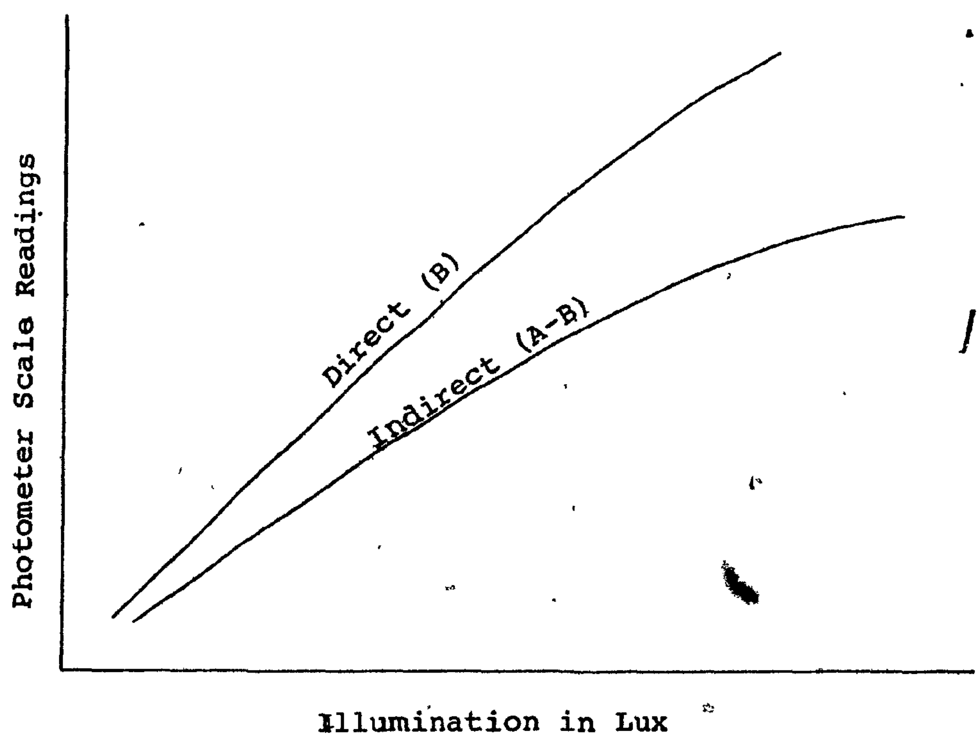
Figure 20

Where mounting heights of lamps are low the total error in the reading can be as high as 40% (54). This method should not be used then in mine haulageways since backs are generally only 3 or 4 m above floor.

Even if one attempts to correct for errors due to the cosine law by carefully recording the angle at which light strikes the photocell face, other factors come into play. For a barrier layer selenium cell, a portion of the light falling on it is reflected from both the surface of the covering filter and the cell surface. The light reflected increases as the angle of incidence increases so that cell response does not follow the cosine law. This is the major source of error when using physical photometers.

Two methods are available to correct for this error. One can read illumination normal to the cell and then use the cosine law to calculate oblique illumination at high angles of incidence. The second method is to determine the cosine response of the cell. The cell is supported on a mounting which permits the angle of incidence from a constant source to be changed. The results of a cosine response test can be reported by plotting relative scale readings against the cosines of the angles of incidence.

Roberts (7) describes a procedure which enables some account to be taken of the effect of indirect light reflected from the surroundings on to the photocell. The photometer is calibrated twice, once for direct light on a photometric bench, and once for indirect light using the interior of an integrating sphere as the source of indirect illumination. Two calibration characteristics are obtained as in Figure 21. The operator still has a problem though as he has to work out the proportions of direct light and indirect light in order to convert the scale readings into illumination values. It also assumes hemispherical illumination for the indirect component, but, as Roberts points out, this is a fair assumption in an arched opening. The method of working out the total illumination is given on page 132.



Illumination versus Photometer Scale Readings

Figure 21

6.5.4 Linearity of Scale Indications The ideal condition of a combined light-sensitive cell and instrument is that unit increases of light falling upon the cell will cause uniform changes in instrument indications. If this condition holds, the response of the cell-instrument is linear. The care used in selecting the cell-galvanometer or cell-microammeter combination and the use of shunts has an important bearing on linearity. In general, the lower the current drawn from the cell, the better the linearity. Consequently, for underground illumination surveys where negligible current flow results, the error loses significance. (2,5)

A test for linearity requires a means for mounting a lamp and cell so that the distance between them can be adjusted readily and measured accurately (61). The relative illumination of the cell will be established by the inverse square law, and is determined entirely by lamp-to-cell distance. Some photometers have a straight line response to incident light but for others a calibration curve may have to be produced. Having calibrated the photometer it may then be applied to determine illumination simply by reference to its meter deflection, knowing the distance from the source and applying the inverse square law, provided one is not too close to the source. Results of a linearity of scale test for low values of illumination and a source temperature of 2360 K are given in Appendix C on page 199.

6.5.5 Wear · Physical photometers should be returned to the manufacturer at specified intervals for recalibration. The check is necessary because of uncertainties in the behaviour of photocells caused by fatigue of the cell or spring or by strain to the microammeter suspension.

Fatigue of a cell can occur following exposure to high intensity light or following an extended period in darkness. Short-circuiting the terminals when not in use is recommended. Spring fatigue may result from allowing a scale deflection to last too long. It can usually be detected by noting the manner in which the dial returns to zero. If it hesitates at a slight upscale deflection and then gradually returns to zero, spring fatigue is present.

Microammeter instruments are delicate. The restoring spring has a weak torque since the photoelectric effect produces only a very small current flow. This means that more stable readings are obtained when the upper portion of an instrument scale is used where the torques exerted by the instrument coils and the restraining springs are greater giving more stable readings with less tendency to stickiness. When possible the range selected for use should be chosen so that the reading is in the upper portion of the scale. The manufacturer's guaranteed accuracy is always expressed in per cent of full scale.

6.5.6 Ambient Conditions Ambient conditions are often extreme in mine work. Ideally a relative humidity of less than 65% and a temperature of 25°C are desirable for the air where instruments are used. In the laboratory this can be achieved but usually in a metal mine relative humidity is higher and temperatures are lower.

Many types of photocells change in sensitivity with change in temperature so that temperature correcting coefficients as supplied by the manufacturer should be applied. All coloured filters used to correct for colour response have appreciable temperature coefficients.

Moisture can condense on insulating surfaces if the humidity is high. It could then act as a high resistance shunt to reduce the total resistance of that part of the circuit (77). For readings in mines, instruments should be rugged and packed with a dessicator.

6.5.7 Technique When measuring low illumination levels underground it is often necessary to light up the scale of the meter. If a cap lamp is used and happens to strike the cell the pointer may immediately swing beyond full scale with considerable force. The tension of the controlling hair spring may alter as a result. The same result can happen if the control switch is placed at the wrong setting.

To avoid this problem a small pen light could be used. The writer found it best to use a fluorescent cap lamp of the type in Figure 26 on page 110. This light source has a large area and the beam is spread effectively by the reflector mounted behind its casing so that the amount of illumination falling on the small surface of the photocell is not high. Another advantage is that this type of light does not produce harsh shadows. If the dial is read with a cap lamp a shadow is created on the dial face by the pointer.

When using the control switch the highest scale reading and hence the lowest deflection should be dialed in first.

Quite often when using the photometer underground an interested spectator or two will congregate. They are tempted to shine their cap lamp onto the cell to test if the pointer will fly to the right. The photometer operator should be aware of this tendency in human behaviour and take corrective counter measures. The instrument should be turned off and preferably covered when strangers approach. Spectators can be told to turn off their lamps, and the area should be cleared of people when readings are to be made.

Since characteristics of the suspension may alter during a survey it is advisable to calibrate the photometer before and after each survey to detect any change in characteristics.

An electrostatic charge may result from wiping the glass cover of an instrument with a dry cloth. This can cause the pointer to take a false position because of the attraction between the glass and the pointer. Breathing on the glass will dissipate the charge (77). Accumulation of static charges can be a problem in the laboratory or in a potash mine where humidities are low but is not worth

39

considering in a metal mine.

6.6 Photographic Photometry Errors

Roberts (59) and Bell (13) discuss the problems inherent in photographic photometry errors. Just as light meters must have a spectral response which is corrected to be near that of the human eye, similarly it is important that the spectral response of the film be close to that of the human eye. Without filters the response is similar to the eye for wavelengths around 0.55 μm but is poor for wavelengths below 0.47 μm or above 0.65 μm.

Irradiation effects can give a blackened area on the photograph which is different from that of the true image. This effect varies according to the average size of the silver halide grains of which an emulsion is essentially composed. Using a fine grained emulsion keeps the effects small but does not eliminate the problem. Long exposure times also cause irradiation effects.

An image of a field of uniform luminance will show reducing density with increasing distance from the negative centre. Although correction factors can be applied they are subject to the normal theory of errors.

The degree of development of a photographic film is dependent on several variables. The main ones are the developing temperature, the developing time, and the type of developing solution. Small fluctuations in these variables cannot be avoided. Known values of luminance must be developed on the side of each photograph for comparison purposes.

On ac systems, incandescent lamps vary in output with the cyclic variations in voltage and current. The variations can affect the film since the film may not receive a mean light value during its exposure time.

6.7 Visual Photometry Errors

The errors likely to be present in the results obtained with a brightness meter are due to:

(1) colour contrast between the two fields
(2) variability on the part of the operator
(3) contrast sensitivity of the eye
(4) imperfect diffusion of the test plate

Considering these factors, the variability of various types of illuminometers has been reported anywhere from ± 2% to ± 10% (5).

6.7.1 Colour Contrast The use of a visual photometer depends on the adjustment of two surfaces to have equal intensity of luminance as judged by the eye of the observer. If the two surfaces are of the same colour the adjustment can be made easily but if the surfaces are illuminated by lights of different colours comparison is difficult.

Several techniques are available to help overcome the problem. One technique is by the use of colour filters. Another is to make the comparison between the two surfaces with the eyes half closed. Another is to interchange the two surfaces rapidly. This latter technique is known as flicker photometry and is incorporated in highly sophisticated photometers as Dr. Blackwell's visual task evaluator (88). It is impossible to retain an accurate idea of the intensity of illumination of a surface even for so short a time as a second. Either the two surfaces must be viewed simultaneously or flicker photometery must be resorted to. Flicker photometery works best when the colours do not match.

In this study colour was rarely a problem. A grey test card was used which closely matched the colour of underground surfaces. Also the colour temperature of the light source shining on the object to be tested was closely controlled to match the colour temperature of the working standard located in the illuminometer. This was done by modifying a miner's cap lamp. A 3 volt ½ amp G.E. #512 incandescent tungsten filament lamp with a colour temperature of 2360 K was used in the cap lamp, in the reference standard lamp and in the working standard lamp. After calibration the cap lamp was connected to the controller (Figure 12, page 62) and was operated from rheostat A in series with battery A.

6.7.2 Operator Variability Using a MacBeth Illuminometer, Morris et al (47) investigated the central tendency and dispersion of measurements made under typical field conditions using five different operators making ten brightness measurements under field conditions and repeating the procedure for six sessions. The mean of this array of 300 brightness measurements was 2.44 ft.L with a standard deviation of $\pm$ 0.12. Several statistical checks were applied to the data to arrive at the following conclusion.

"An operator who characteristically makes small variable errors and whose constant error is known can yield data from which accurate estimates of brightness can be made. Without specific knowledge of the performance characteristics of an operator the mean of a series of measurements from several operators is more likely to be an accurate estimate of a source than mean of measurements from a single person. It would appear that this last generalization holds even when the mean of several operators is based on fewer measurements than that for a single operator, although our data do not indicate the minimal number of measurements necessary to make a decision on whether to use a group or an individual."

Since it would appear that little confidence may be placed in the mean of a small number of readings from a single operator it was decided that at least seven observations would be made on the test card and on the object under test(Table 20, page 209). Since even the mean of a large number of readings from an operator would be inaccurate unless the constant error of an operator were known the MacBeth Illuminometer was not used to measure brightness but was used to measure reflectivity. Since this is calculated by obtaining the ratio of two brightness measurements and multiplying it by the known reflectivity of the test card any errors in the brightness measurements would tend to cancel each other out. This occurs because the large number of readings increases the confidence that the constant error for both sets of measurements is the same.

Operator variability was checked in the field by having two operators work out the reflectivity of a surface under test. Whenever this was done it was found that, although the two operators could not agree precisely on the brightness of the test card and the surface under test, they always agreed on the reflectivity of the surface under test.

As an added check that operator variability would not contaminate the results a test should be performed that the operator can be classified as having a C.I.E. average eye (Committee Internationale de l'Eclairage). For an average eye a wavelength of 0.555 μm produces maximum visibility per unit of energy expended when the eye is functioning as it normally does in daylight. This lies between yellow and green. If the wavelength increases or decreases, relative visibility decreases. Radiant energy of wavelength 0.555 μm is given a relative visibility of 1.0 and the average eye is defined as one in which the relative visibility factor changes throughout the visible spectrum as shown in Table 8. (4).

TABLE 8

RELATIVE VISIBILITY FACTOR OF THE C.I.E. AVERAGE EYE
(RELATIVE VISIBILITY AT 0.555 μm 1.0)

WAVELENGTH μm	RELATIVE VISIBILITY	WAVELENGTH μm	RELATIVE VISIBILITY	WAVELENGTH μm	RELATIVE VISIBILITY
0.40	0.0004	0.52	0.710	0.64	0.175
0.41	0.0012	0.53	0.862	0.65	0.107
0.42	0.0040	0.54	0.954	0.66	0.061
0.43	0.0116	0.55	0.995	0.67	0.032
0.44	0.023	0.56	0.995	0.68	0.017
0.45	0.038	0.57	0.992	0.69	0.0082
0.46	0.060	0.58	0.870	0.70	0.0041
0.47	0.091	0.59	0.757	0.71	0.0021
0.48	0.139	0.60	0.631	0.72	0.00105
0.49	0.208	0.61	0.503	0.73	0.00052
0.50	0.323	0.62	0.381	0.74	0.00025
0.51	0.503	0.63	0.265	0.75	0.00012

Louis Laferrière was the principal operator of the illuminometers used in this research project. Other operators employed in the study were Miss Camille Dow and the writer. Mr. Laferrière was tested at the National Research Council, Division of Physics, Ottawa and found to conform to the definition of a normal observer. Miss Dow and the writer both consistently produced photometric observations which agreed with those of Mr. Laferrière. Therefore both can be considered as normal observers during the period this research was conducted.

6.7.3 Contrast Sensitivity The accuracy of measurement is limited by the decrease of the contrast sensitivity of the eye at low brightness levels. Mine surfaces have poor reflectivities to start with. With both large irregular shaped openings and irregular lighting low brightness levels often result. Visual photometers then are suitable for illuminance measurements but should not be used for luminance measurements.

In this research project visual photometers were used only for reflectivity measurements. In this work a portable light source is used giving luminance values in the 30 asb range. At this level of luminance loss of contrast sensitivity is not a major source of error.

6.7.4 Imperfect Diffusion of the Test Plate In order to calibrate the MacBeth Illuminometer the reflectivity of the test plate must be known. Yet the reflectivity of any surface is not a constant but varies according to the angle of incidence and the angle at which it is viewed. This value of the reflectivity of the test plate is used in a comparison of other surfaces to determine reflectivity, illuminance, or luminance so the conditions under which it is observed must be carefully controlled. A special glass surface was used as the test plate when using the MacBeth Illuminometer. For this surface the angle of incidence can be varied either 30^{o} to the left or the right of normal without affecting the reflectivity of the surface. Figure 14 on page 64 compares the percentage error for this surface and two other common test plate surfaces over a wide range of incident angles. The unique feature of the special glass is indicated by the long vertical line immediately above the zero per cent error indication. Since the reflectivity of any surface also varies with the colour temperature care was taken to ensure that the test plate was always viewed under the colour that it was calibrated at by the manufacturer.

Kodak test cards were also used in conjunction with the illuminometer. These were calibrated by the National Research Council, Division of Physics (108), and when used as standards in the field, viewing and recording angle geometry as well as colour temperature were made to coincide with calibration parameters. In this manner errors were kept minimal.

CHAPTER 7

MINE LIGHTS

7.1 General

The invention of the flame safety lamp in 1815 solved the problem of providing illumination without the risk of explosion. The introduction of the electric cap lamp in the 1920's virtually eliminated nystagmus. Today the problem is to provide the quantity and quality of light best suited to give maximum benefits in terms of safety, performance and morale at minimum cost.

Several types of light sources are suitable for underground use, each having inherent advantages and disadvantages. Detailed descriptions of their method of operation, distribution of light output, range of sizes, etc. are available from manufacturers' handbooks (122,126,127,130,133,135,137). Using this data and the experience gained by other mine operators, industrial engineers could weigh the merits of the various types of sources as applied to their own particular situation.

This chapter describes various types of light sources found in visits to Canadian mines and reports operator opinion on their use. Possible future trends in mine lighting are noted and factors affecting the illumination produced by any fitting are explored.

7.2 Tungsten Filament Lamps

This is the most common type of lamp in use in underground mines but it is being replaced by more efficient types of light sources. It is also referred to as an incandescent lamp since the tungsten filament is heated to incandescence by an electric current. Tungsten is almost always the filament material.

Tungsten filaments operate between 2500 K and 3300 K causing the filament to emit radiations in a continuous spectrum although not in the same proportions as daylight. A white light is produced. A tremendous variety of lamps are available on the market. Sizes range from 0.1 W to 20 000 W. Variations in bulb shape, socket thread, and filament design occur as well. Filament design is a careful balance between light output and life.

Lamp efficiency varies directly with filament temperatures. Coiling of the filament increases efficiency. Compactness, mechanical strength, and minimum heat loss are provided by coiling filaments in single, double or triple coils with size varying according to the power and duty involved. Theoretically, a tungsten bar at the melting point would yield 52 lm W^{-1}, but the highest efficiency of a standard lamp listed in a lamp catalogue is 33 lm W^{-1} and the lowest is 4 lm W^{-1}. Source brightness is high ranging from about 3×10^7 asb for clear lamps to 3×10^5 asb for inside frosted lamps. The most efficient lamps have the shortest lives. In choosing a tungsten filament lamp, lamp cost must be weighed against the cost of electricity. Generally a lamp life at 750 h to 1000 h is most economical with life ratings varying from 5 h to 1500 h.

Line voltage affects efficiency. For a specified watt filament, lower design voltage requires a larger wire diameter to handle the higher current. This results in a more rugged lamp. Gas losses are less with these thicker filaments. Consequently, lamps for 120 V service are more efficient than 240 V lamps. Usually highest efficiencies are achieved from 12 to 20 V. Below this range, conduction losses to the lead wires overcome reductions in gas losses. If lamp input voltage fluctuates widely, control devices are necessary to prevent noticeable variation. A 10% drop in voltage can cause a 70% drop in output. For mine work, rough service lamps or vibration service lamps are used because of shock waves from blasting. Vibration service filaments have more supports than general service filaments. Efficiency is lower since the additional supports dissipate heat. Rough service filaments have more supports and lower efficiency.

Bulb blackening, caused by tungsten evaporation, is a serious problem in vacuum lamps. This can be reduced by filling lamp bulbs with an inert gas. Unfortunately filling gas conducts some heat away from the filament, causing a reduction in efficiency, particularly for low watt lamps. Lamps below 40 watts are still of the vacuum type because the heat loss introduced by the gas offsets the advantage gained by the lower rate of filament evaporation.

The filling gas is usually a mixture of nitrogen and argon. Other inert gases have lower heat conductivities than either nitrogen or argon but are too expensive for use in general service lamps. They are practical though in miners' cap lamps where high efficiency is desirable to minimize drain on the battery (48). All countries use tungsten filament bulbs for cap lamps. The most common filling for cap lamps is krypton which is introduced at slightly less than atmospheric pressure.

A tungsten filament system is the least expensive in terms of initial equipment investment, being about $0.15/1000 lm. The system is flexible. Wattage for a given lampholder can be changed easily by simply inserting another lamp. Using Spencer cable, lamps can be installed quickly at any desired spacing. They can be operated on either AC or DC. No flicker is evident on 60 Hz power. Light output reaches its maximum about 0.001 s after power is applied.

They are, however, often vulnerable to shock and vibration. Filaments are easily broken. Most of the energy is given off as heat so that fixtures have to be made of special material. The glowing filament is not safe in an explosive atmosphere. The light source in a tungsten filament lamp is small and the glare is appreciable as compared with discharge lamps in which the light source is large and the glare is small.

7.3 Tungsten Halogen Lamps

These lamps are similar to the tungsten filament lamp. The tungsten filament is enclosed within a quartz envelope rather than a glass envelope and halogen gas is added to the inert filling gas. Iodine is the most common halogen gas but sometimes bromine is used.

The halogen gas prevents tungsten from depositing on the inside surface of the quartz bulb by a process known as the "iodine cycle". In the iodine cycle, evaporated tungsten returns to the filament so that the inside walls do not blacken. If they are operated at less than their stated power, the heat generated by the filament may not be sufficient to maintain the halogen regenerative cycle. This results in a greatly reduced lamp life.

A glass bulb cannot be used since a high bulb temperature is required to maintain the halogen degenerative cycle. In order to cut down on heat loss the lamps are generally smaller than comparable tungsten filament lamps. Small size is accomplished by using a tightly wound filament.

Tungsten halogen lamps have a very high source brightness, being around 5 X 10^7 asb. Efficiency is higher than tungsten filament lamps with 20 to 27 lu W^{-1} being reported. Colour temperature range is between 3000 K and 3400 K giving a whiter light. Lamps are available between 45 and 5000 W giving life variations between 2000 and 5 h. This is a greater life expectancy than a tungsten filament lamp. The manufacturer claims the average life of a 500 W G.E. Quartzline lamp is twice that of the regular 500 W lamp.

Lamp seals are more fragile than tungsten filament lamps and capital cost is roughly five times higher, being about $0.77 per 1000 lu.

7.4 PAR (Parabolic Aluminized Reflector) Lamps

PAR lamps have modifications to the finish and shape of the bulb so that the light source is accurately focused by a self-contained optical system. Silver or aluminum is applied to some portion of the glass or quartz bulb to control the light distribution from the filament by reflection. Often a portion of the glass bulb is shaped into a parabola. The parabolic area is silvered and the lamp is a complete lighting system with source reflector, and lens. The parabolic shape of the reflector produces a narrow beam of light if the filament is located at the focal point of the reflector. If the front cover lens is cut into prisms or stipples, light is projected into desired beam patterns.

An example of a PAR lamp is the sealed beam headlight used on scoop trams. With sealed beams the light source is a tungsten filament but one Canadian mining company is experimenting with quartz halogen lamps on their scoop trams. Conversion kits are on the market.

The quartz halogen lamp is more common on European vehicles. It is undoubtedly a superior lighting system and has a longer life because of the "iodine cycle". One manufacturer

300W Tungsten Filament (bottom)
and 500 W Tungsten Halogen (top)

Figure 22

PAR Lamps and Fixtures

Figure 23

claims its halogen lamp on high beam will probe 800 m into the night as opposed to about 500 m for sealed beams(119). The reluctance to convert on this continent is probably due to the cost of the lamps and the fear that the powerful headlights might blind oncoming drivers. Usually though the design of the lens aims the light ahead and to the right to reduce glare.

A PAR mercury-vapour lamp is also manufactured for use as a machine headlight. This headlight is now finding good acceptance throughout the industry (93). This is because it has a life about ten times greater than the tungsten filament lamp and provides from 30 to 65 lu W^{-1}. The sealed beam only provides 12 to 22 lu W^{-1}.

PAR Lamps are available in sizes between 25 W and 1500 W. They are large in comparison to conventional lamps since they have a self-contained optical system. They are usually more rugged with stronger supports on the filament giving them a greater resistance to vibration and shock.

7.5 Fluorescent Lamps

The fluorescent lamp is an electric discharge lamp consisting of a long tube containing mercury vapour and electrodes sealed at both ends. When a suitable potential difference is maintained between the electrodes, the gas is excited and a current flows. The radiation from the gas discharge is a broken spectrum (page 16) with only a small portion of the energy emitted in the visible blue portion of the spectrum. The larger portion of the liberated energy is in the ultra-violet region between 0.2 and 0.3 μm.

The molecules of certain silicates, tungstates, borates, and phosphates can react to ultra-violet radiation in a most useful way. These substances are coated on the inside of the glass tube as a powder. The powder is excited by the ultra-violet radiation produced by the low pressure mercury vapour arc discharge and re-radiates this absorbed energy as visible light when it returns to its ground state.

Yantz (110) describes the several means available to initiate the low pressure mercury discharge. Some systems require pre-heating the electrodes whereas other systems depend on a high voltage pulse with cathodes at a much lower temperature. Ballasts are required to provide sufficient starting voltage and limit current flow. A combination incandescent-fluorescent lighting unit gives instant start and blended light (81).

With the cold cathode lamps a variety of tube shapes are possible because the low arc current densities are not seriously affected by the sharp bends in the glass tubing. Forty watt, 10 inch diameter circular fluorescent tubes are commonly used in underground lighting in England (72).

The fluorescent lamp offers several distinct advantages over tungsten lamps in mine lighting. Longer life, higher efficiency, better colour rendition and lower surface brightness make this lamp increasingly more popular (73).

The life of a fluorescent lamp is considerably greater than that of a tungsten filament lamp so that the number of lamp changes required per year is correspondingly reduced. Tungsten-filament lamps have reduced lives under mining conditions since vibration and shock cause excessive filament breakage. The hot cathode fluorescent lamp has only short filament heaters at each cathode so is not so susceptible to vibration and shock failure. The electrodes are well supported and the lamp bulb is strong. Lamp life ranges between 500 and 30 000 h depending upon the size of the lamp.

The efficiency of the fluorescent lamp is about three times that of a tungsten lamp. It varies between 35 and 85 lu W^{-1}.

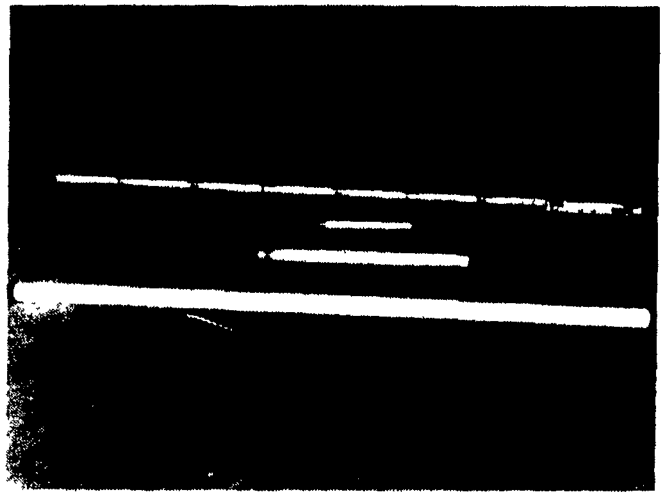
Colour rendition depends upon the mixture of powders coating the tubes. Since the colour of light is uniquely defined by its frequency, the different powders or phosphors are a means of obtaining light of a chosen colour(69). With proper choosing a natural colour can be obtained. Known as "warm white" this phosphor coating has good colour rendition with a colour temperature of approximately 4500 K. This natural daylight colour of fluorescent lamps is important in mining work where all illumination is necessarily artificial. A highly efficient pale apple green tube is especially recommended for coal face lighting both because of the high lumen output and its high aesthetic value in underground conditions (72).

Avoidance of glare is important in mining work particularly since the eye is adapted to low illumination. With low mounting heights glare is almost unavoidable with tungsten lamps if a reasonable level of illumination is to be obtained. A bright light source dazzles the eyes and makes seeing more difficult rather than easier. The long fluorescent tube gives a better distribution of light resulting in no harsh shadows. Tubes are available in lengths up to 2.5 m and diameters of 5 cm. This large illuminating area gives a low brightness and reduces the possibility of glare. Source brightness of fluorescent lamps range from 16 000 asb to 65 000 asb. An assortment of fluorescent tubes is shown in Figure 24 and a typical installation is shown in Figure 25.

A fluorescent cap lamp has recently been developed by Ocean Energy (132) and adapted for mining purposes under contract with the U.S. Bureau of Mines. Using the smallest tube shown in Figure 24 it operates on the same battery as a standard lamp and supplies a broad flood beam. It can operate for the same 10 hour duration as a standard lamp and produce four to five times the lumen output.

Its main advantage is to improve peripheral illumination which is a welcome aid to mechanics or timbermen who do not require the high intensity spot of the standard cap lamp. Since these trades tend to work in crews the fluorescent lamps augment each other and give good area illumination for greater safety and efficiency.

One disadvantage is its large size and unusual appearance



Assorted Fluorescent Tubes
Figure 24

Refuge Station Illumination Using Fluorescent Fixtures—Brunswick Mine
Figure 25

(Figures 26 and 27). It is about 125 g heavier than a standard incandescent cap lamp and lacks the high intensity spot which many miners prefer.

Fluorescent lamps are now being used for general area illumination around mining equipment. Mounted right on the equipment and operating from a 12V battery, six sizes from 8 W to 40 W are available. Figures 28 and 29 show 20 W fluorescent lamps on a jumbo drill at Gaspé Copper. Jumbo operators and helpers all liked the area illumination these lamps provided and preferred the lamp fitted jumbo. Fittings can be obtained from the Magna-Beam Division of Ocean Energy.

7.6 High Intensity Discharge Lamps

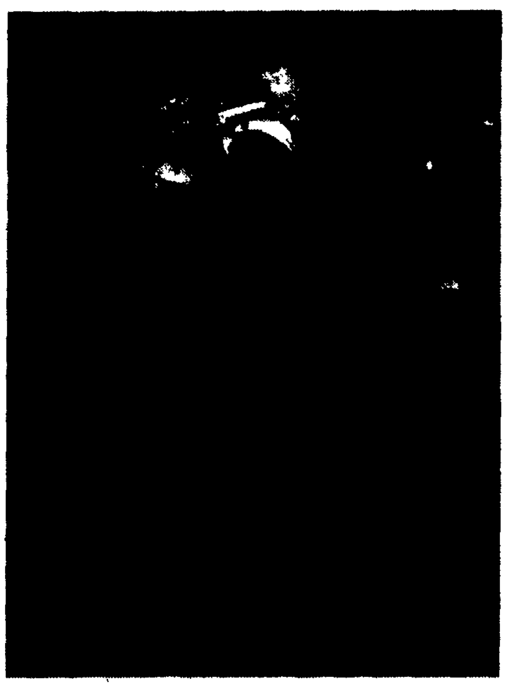
A variety of radiation sources are possible with this type of lamp. Their common characteristic is that they consist of gaseous discharge arc tubes which operate at pressures and current densities sufficient to generate desired quantities of radiation within their arcs. All high intensity discharge lamps have a negative resistance characteristic and ballasts are required to supply necessary starting voltage and limit the current. All produce 120 Hz flicker which is rarely an annoyance.

Three categories of high intensity discharge lamps are in use in mines. These are

(1) Mercury Vapour Lamps
(2) Metal Halide Lamps
(3) High Pressure Sodium Lamps

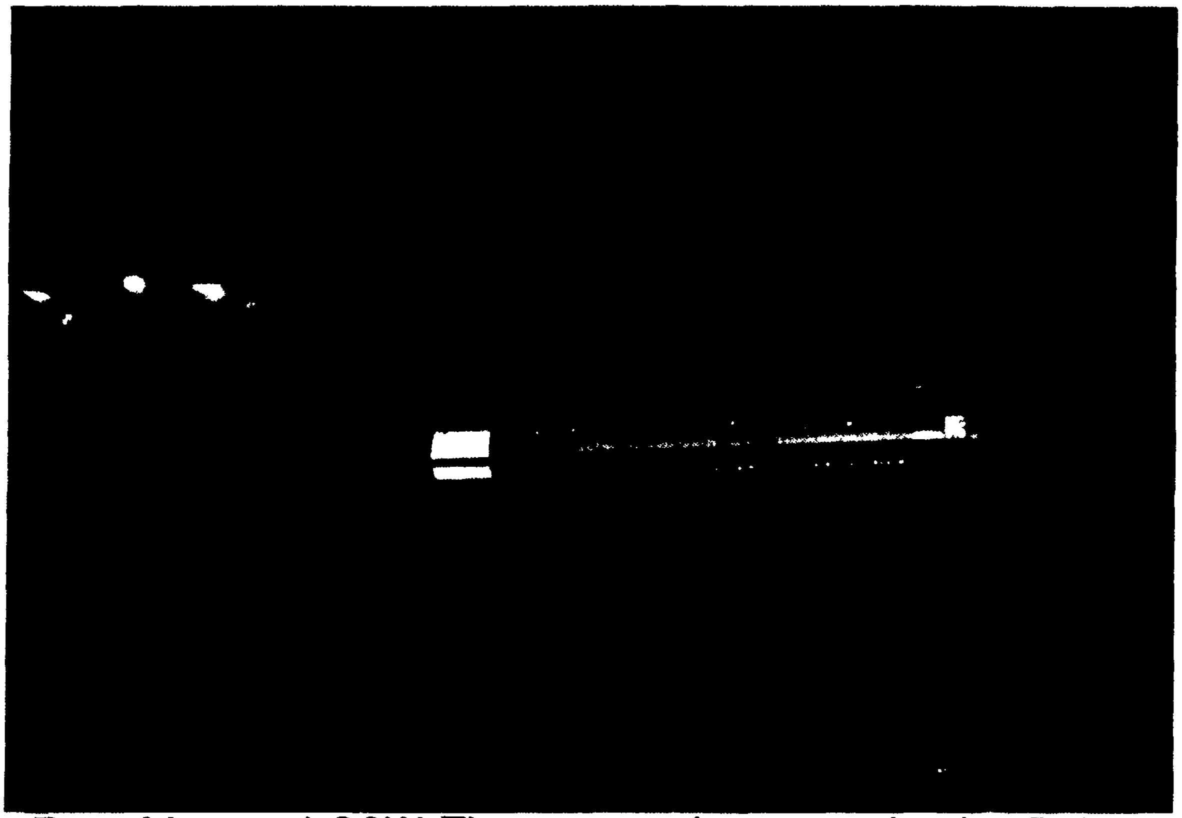
A Newly Developed Fluorescent Cap Lamp

Figure 26



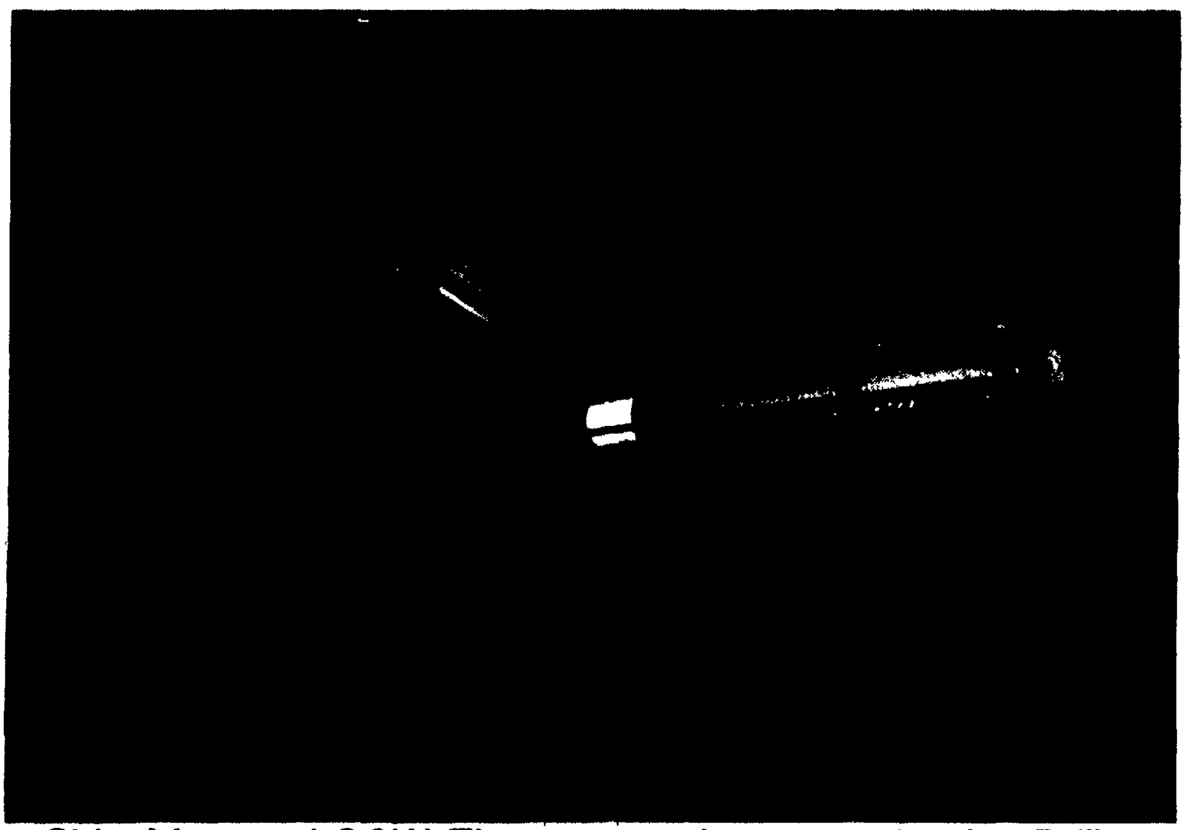
Fluorescent Cap Lamp and Battery

Figure 27



Rear Mounted 20W Fluorescent Lamp on Jumbo Drill— Needle Mountain

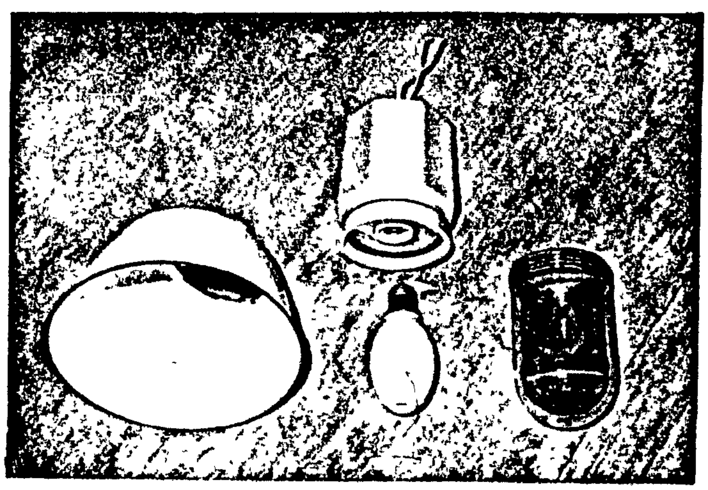
Figure 28



Side Mounted 20W Fluorescent Lamp on Jumbo Drill— Needle Mountain

Figure 29

7.6.1 Mercury Vapour Lamps Collisions between electrons and mercury atoms in the arc ionize the mercury atoms to produce the characteristic spectrum of mercury. This occurs when the outer electrons of mercury atoms return to their normal state and release radiant energy in the transition. Some energy is in the ultraviolet region and is absorbed by the glass envelope. If fluorescent powders are coated on the inside of the envelope the ultra-violet radiation can be converted to visible light. If this is done the lamp is usually called "colour improved". The phosphors produce red light which enhances the blue appearance of the mercury arc spectrum. Mercury vapour lamps are very bright, being about 4.6×10^6 asb for a clear lamp down to about 0.4×10^6 asb for a colour improved lamp. Figure 30 shows a small colour improved mercury vapour lamp.



A Compact Mercury Vapour Lamp

Figure 30

Colour improved versions have a lower brightness since the outer envelope is the apparent light source. Clear arc tubes have a source size from 2.5 cm to 10 cm long and 1 cm to 2.5 cm in diameter depending on the wattage. They are usually available in sizes between 50 W and 3000 W.

The lamps are widely used in mine lighting for several reasons. Being a high intensity discharge lamp there is no filament to break. Expected lamp life is between 10 000 h and 24 000 h resulting in far fewer bulb changes. Efficiencies of between 35 to 60 lu W^{-1} is much higher than for incandescent lamps.

One drawback to the lamp is the long warmup period required for the light to reach full brightness (7 to 9 min.). Approximately 5 min. is required for restart immediately after a power interruption. In addition, intensity of the lamps is high, causing glare problems. The large selection of sizes though can allow the designer to minimize objectionable glare. Recent models have a diffusing lens which disperses the light in random directions and reduces surface brightness. Figures 31 and 32 show mercury vapour garage lighting in two different mines. All shop personnel questioned liked the general area illumination. Mounting heights in both instances was over 6 m so that glare was not a great problem.

Patts (106) reports on the use of mercury vapour lamps mounted on mobile mining equipment in the United States. Direct current operation of mercury vapour lamps is possible

Underground Garage Illumination with Mercury Vapour Lamps
(Brunswick Mine)

Figure 31

250 Watt Mercury Vapour Lamps with 40 Watt Fluorescent Bench Lighting — (Strathcona Mine)

Figure 32

with a resistor ballast to control the arc current. Results were encouraging. D.C. operation though would create high power losses, high heat, and its attendant maintenance problems.

7.6.2 Metal Halide Lamps These lamps are similar to mercury vapour lamps but contain metal halide additives in the form of sodium iodide, thallium iodide and indium iodide. These additives produce red and yellow light which, when mixed with the blue and green of the mercury vapour, give a better colour quality, higher source brightness, and a greater efficiency than the mercury vapour lamp. The arc tube source varies between 1 cm and 5 cm in length and from about 1 cm to 2.5 cm in diameter. It is made of fused quartz with a special end coating designed to keep the ends hot to maintain evaporation of the iodides and metallic ions. A starting electrode and resistor in the lamp aid in striking the arc. Common sizes are 75 W, 400 W, 1000 W, and 1500 W. All are of rugged construction to resist vibration and shock.

Higher open circuit voltages are required for starting and DC operation is not recommended. Ballasts must provide sufficient starting voltage and proper wave shape to operate the lamp successfully. Because of the high voltage requirements operational life is shortened. Another disadvantage is that restrike time and warmup time to full brightness takes from 10 to 15 min.

7.6.3 High Pressure Sodium (Lucalox) Lamps Lucalox is a trade name of General Electric which is used regularly in lighting vocabulary. The construction, operation and radiation characteristics of Lucalox lamps are unlike those of the other high intensity discharge lamps. The lamp was made possible by the invention of a translucent ceramic arc tube and a process for sealing special electrodes in the tube to withstand high temperatures and the corrosive effects of heated sodium vapours. The arc stream consists principally of alkali metal vapours maintained at very high temperatures within the compact ceramic arc tube giving good quality light, with a golden yellow cast. The bulbs generate typically 110 to 115 lu W^{-1} which make it a highly efficient source of light. It is basically a high powered lamp with sizes of 250, 400 and 1000 W presently available. The lamps attain full output in less time than mercury lamps and life expectancy ranges from 6000 to 15 000 h.

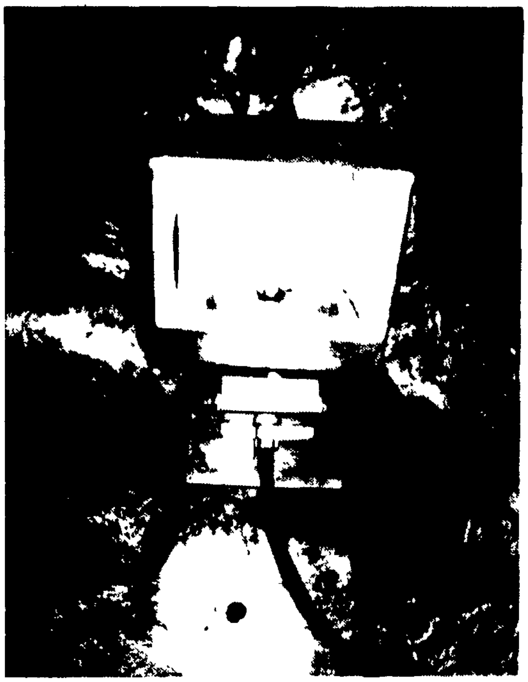
One problem with the lamp is that DC operation is not recommended. Input power is usually 480 V a.c. with a ballast providing the necessary open circuit voltage to strike the arc. Originally they required separate cables to each lamp and they were heavy, weighing about 20 kg per fixture, but these problems have been surmounted. Fixtures now have self-contained ballast units in the lamps so that the lamps can be strung in daisy-chain fashion. Weight has been cut to about 10 kg.

High pressure sodium lamps offer great promise as an underground light source and are being tried in some Canadian mine operations. At Thompson T1 mine, two stopes are presently receiving general area illumination with these lamps. Results are favourable and two more stopes are scheduled to receive the lamps. At Needle Mountain illumination is obtained with sodium lamps. Figures 33 and 34 are photographs of one of the lamp installations and Figure 35 shows a section of the roadway receiving illumination. Figure 36 is a wiring schematic for a six lamp installation on the ramp.

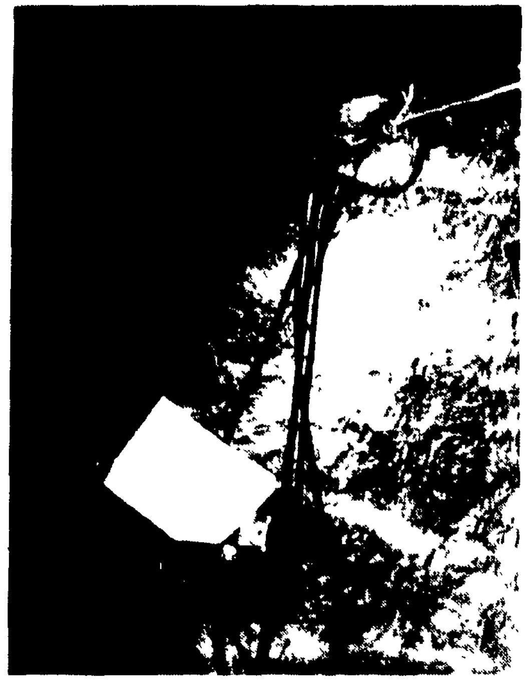
7.7. Low Pressure Sodium Lamps

Recent developments in low pressure sodium lamps have made them economically attractive. The lamp consists of a U-shaped tube contained inside a cylindrical glass envelope. An indium oxide coating on the inside of the outer glass envelope reduces thermal loss and improves efficiency. A small quantity of sodium is operated inside the U-shaped tube at a temperature around 230°C. Neon, argon, xenon and helium gases are also present to aid in starting. A high vacuum is applied inside the outer glass envelope to prevent convection heat losses from the arc. When first started, the lamp appears red due to the neon discharge, but this gradually gives way to the characteristic yellow as the sodium is vaporized. The lamp may require 15 min to reach full brightness and 1 to 2 min to restart after a power failure.

Source brightness of low pressure sodium lamps is much

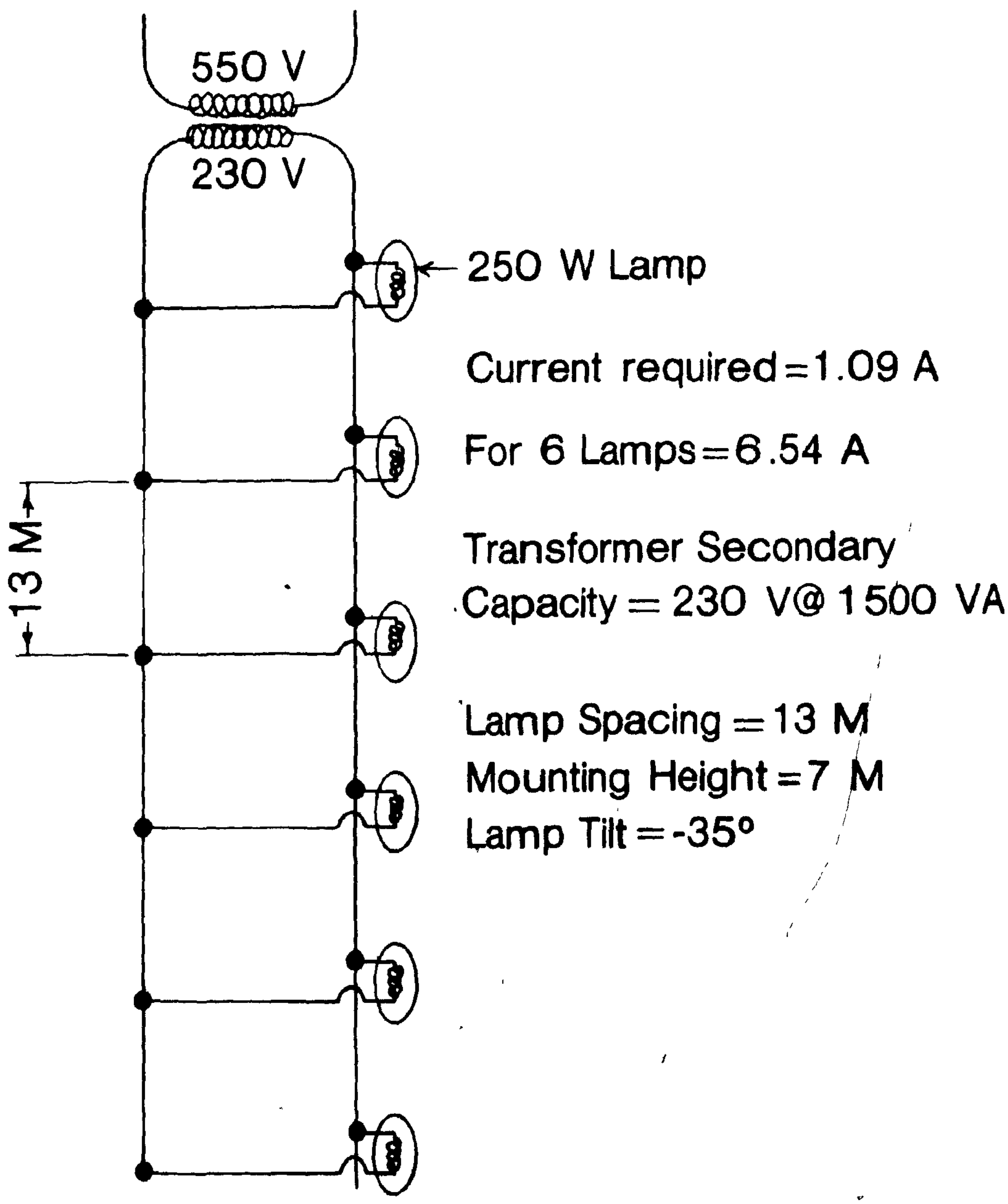


Sodium Lamp – Front View
Figure 33



Sodium Lamp – Side View
Figure 34

Ramp. Illumination by Sodium Lamp
Figure 35



Sodium Vapour Lamps — Wiring Schematic
Figure 36

lower than other arc discharge lamps at about 3 X 10^5 apostilb. Lamp life varies according to burning position but ranges between 8000 h and 12 000 h. Luminous efficiency is very high at about 178 lu W^{-1} for the new indium oxide coated lamps. This is the most efficient light source commercially available. Colour rendition is poor because the light output is monochromatic giving the characteristic yellow typical of the sodium element in the incandescent region of the bulb. Only a few select wattages in the 35 W to 200 W range are commercially available. Again DC operation is not recommended.

There is evidence that acuity in monochromatic light such as that of a low pressure sodium vapour lamp is better than that in light of a continuous spectrum. All the light rays passing through the lens of the eye are refracted to an extent depending on their wave length. White light, containing all the spectral colours, therefore produces many images of the object viewed, all at different distances from the lens. These cannot all be focused accurately upon the retina. The brain ignores this and interprets the images without showing us coloured boundaries but nevertheless they are not so sharp as they are in monochromatic light, where aberration cannot occur. Monochromatic light produces only one image and permits easy and accurate focusing. Further research is needed to determine the importance of the benefit to mine lighting.

Evidence also exists that transmission losses are reduced with the use of low pressure sodium lamps (10).

7.8 Comparison of Mine Light Sources

Table 9

Type of Source	Effic ($lu\ w^{-1}$)	Brightness (asb)	Life (h)	Cost ($(10^3\ lm)^{-1}$)	D.C. source
tungsten filament	4-33	$0.3x10^6$ to $3x10^7$	750 to 1000	$0.15	yes
tungsten halogen	20-27	$5x10^7$	5 to 2000	$0.77	yes
fluoresc.	35-85	$0.16x10^6$ to $0.65x10^6$	500 to 30 000	$0.81	yes
mercury vapour	35-60	$0.4x10^6$ to $4.6x10^6$	10 000 to 24 000	$0.66	yes
metal halide	80-90	$1.6x10^7$	6000 to 10 000	$1.00	not advised
high pressure sodium	110-115	$2.3x10^7$	6000 to 15 000	$1.18	not advised
low pressure sodium	178	$3x10^5$	8000 to 12 000	$0.73	not advised

7.9 Lamp Illumination Factors

The study of the installation of fixed lighting units underground has received limited attention. Each manufacturer of underground lighting fittings has his own particular way of designing mine lighting layouts using empirical methods, and these are based on the knowledge of past and existing schemes. A need exists to put the subject of underground illumination on a sound scientific basis to keep pace with developments in the other fields of mining.

The mine environmental engineer should be aware of the important criteria in designing a lighting system. Any lighting scheme design should take into account the major factors affecting the illumination produced by the fitting. These are:

(1) the shape of the working place
(2) the reflectivity of the back, sides and floor
(3) the position and orientation of the fitting
(4) the ambient conditions

Factors can be determined either by underground measurements or from the manufacturer. The factors can then be used to predict the illumination system required for any conditions, by either employing monographs (12), coefficients of utilization (9), and the use of the Zonal Cavity Method (4,11). Potts and Bell (54) quote examples to show that designs of underground lighting systems based wholly on the knowledge of existing installations do not lead to the most efficient light utilization. Although surface installations are amenable to empirical methods of lighting design, underground lighting is unique because of the many more variables and the large range these variables may have. Once the variables are measured various techniques are available or new techniques can be developed to design the installation (4,15,35,50,60,71 84,111). Again, this is an area requiring more research.

7.9.1 Shape of Working Place The cross-sections of underground working areas differ widely. Disregarding the uneven appearance of walls and back, general shapes encountered include rectangular, elliptical, semi-circular and arched. These shapes can be employed to enable the mounting position of a light fitting to be expressed numerically. As an illustration, a mounting position parameter can be defined as the ratio of the width of the opening at the height of the lighting fitting to the width at the floor. Then a fitting mounted at the top of an arched back would have a position parameter of zero whereas a fitting mounted at the bottom of the arch has a position parameter of one. Knowing the flux distribution of the fitting the problem of the best position parameter can be solved. Another problem unique to mine lighting is the cramped condition of the working area. With low backs glare becomes increasingly important necessitating the use of low brightness light sources.

7.9.2 Reflectivity The useful light which enters the eye is reflected light. Since the designer is concerned with the ability to see and not necessarily with the way in which a source illuminates, the emphasis should be placed on reflected light and not on the source of the light. The amount of light which gets reflected from the floor, sides and back should be known and some account made for the conditions of the sides and back. The light reflected by the sides and back of a roadway will travel in all directions in varying proportions providing the sides and back are smooth. If they are rough and rock protrudes into the area to be illuminated some light from the fitting and some of the reflected light will be prevented from reaching the working plane because of absorption and reflection by these jutting surfaces. Reflectivity is discussed in detail in Chapter 9.

7.9.3 Position and Orientation of Fitting One aspect of the positioning of the lamp has been discussed in section 7.9.1 since it ties in closely with the cross-section of the working place. The orientation of the fitting is important since the beam spread is usually controlled by reflectors. Proper orientation is usually determined by the mounting height. Figure 40 on page 138 illustrates the effect on roadway illumination with incorrect orientation and with correct orientation. Poor orientation results in a section of the roadway under the lamp not receiving any illumination. With straight fluorescent tubes a further variable is the alignment of the tube in the working area. Tubes have been aligned both transverse and longitudinal. Most writers state that longitudinal mounting is most effective (71).

7.9.4 Ambient Conditions The humidity of the air, the velocity of the air flow, and the temperature of the air all affect the working temperature of the lamp and hence its light output and its life. These factors should be considered when calculating replacement costs and lamp efficiency. Of greater importance though is the presence of dust and fog. Dust suspension or fog in the air stream can cause serious transmission losses. Good ventilation practises can cut down on dust and some research has been done on fog control (74). If dusty conditions prevail a periodic cleaning of the lamp is warranted since depreciation of the light output from the source due to dust deposition on the cover can be considerable.

7.9.5 Flux Distribution of the Fitting This is obtainable from the manufacturer and can be checked in a suitably equipped photometric laboratory. Once the characteristics of any fitting are known the cost of using such a fitting can be calculated and a decision made as to which of the several types of fittings would best serve the purpose. Mine lighting fittings should be chosen on flux distribution bearing in mind cost, life and maintenance.

7.10 Expected Trends in Mine Lighting

Electric power is playing a greater role in mechanized mining. One illustration is the advent of electric scooptrams in cut-and-fill stopes. The advantage afforded in terms of improved air quality virtually assures their general acceptance.

Since electric cables have to be strung into the working places for machine operation it will be a simple matter to tap off some power to given general area illumination. This lighting would be either wall mounted or tower mounted depending on working area dimensions. Using an a.c. source would reduce maintenance by eliminating the necessity of charging and servicing batteries.

Of the a.c. light sources available the most promising are the gaseous discharge lamps. Although they require some sort of control to limit the current which they will take, their efficiency more than compensates for this extra hardware. The output of a tungsten filament lamp is about 10 lu W^{-1}, that of a mercury vapour lamp 35 lu W^{-1} and a sodium vapour lamp as high as 178 lu W^{-1}. Most of the breakages of lamps at working places are caused by breakage of filaments by vibration. Discharge lamps have no filaments to break. Even without vibration damage, the average life of a tungsten filament lamp is 1000 h while that of sodium and mercury vapour lamps is over 2000 h. A further advantage is in the reduction of glare.

Hopefully a breakthrough in technology will occur in the miner's cap lamp. The fluorescent cap lamp was an attempt to get away from the tungsten filament lamp but as pointed out on page 107, it has its drawbacks. Perhaps a quartz halogen or a mercury vapour cap lamp could be produced since both can operate on D.C. A major problem would be to overcome the heat generated. Tungsten-halogen lamps run hot to maintain the iodine cycle (page 101) while mercury vapour lamps operate hot because the power is concentrated in the small quartz tube.

A new type of light bulb should soon be on the market. It operates on a principle similar to that of fluorescent lights, except that it does not use electrodes and will screw into a conventional lamp socket. The bulbs can last 10 years and save 70 per cent of the energy an ordinary incandescent light would use. Although initial cost would be high, up to $10 each, in the long run they would be more economical than tungsten filament because of the electricity saved. The bulbs would find their greatest application in mines which are already using tungsten filament bulbs since they already have the necessary wiring and sockets installed.

Fibre optics could be employed in mine illumination. Certain highly refractive substances can be manufactured in long tube shapes. When light is shone down these tubes, they allow light to travel through them and be "bent" around corners. A small amount of light escapes all along the tube so that the tube acts as a secondary source of light. If the tubes were wrapped around a machine or around the walls of a stope they would aid the eye in identifying important objects. Source brightness would be too low though, to provide general area illumination but benefits should be realized by a reduction in machinery damage and a general improvement in safety.

Although most research is geared to improving the light source, it is important that the harmful effects of glare not be overlooked. One of the approaches employed by Crouse-Hinds to eliminate glare is the ingenious use of polarized light (28). The method involves putting a circularly polarized "glass" or plastic sheet all around the light bulb and having the miner wear eye shields of opposite rotational polarity over his safety glasses. A miner who thus looked at a powerful light, such as a Lucalox bulb, would see only a very dim light, the double polarization having reduced the intensity considerably. The rest of the area would be well illuminated since the light bouncing off these objects would not be polarized. Many Canadian mining companies make the wearing of safety glasses mandatory anywhere on company property. If the safety glass itself could be made of polarized glass the scheme would not be hard to implement.

SECTION II

MEASURING AND ESTABLISHING LIGHT PARAMETERS

CHAPTER 8

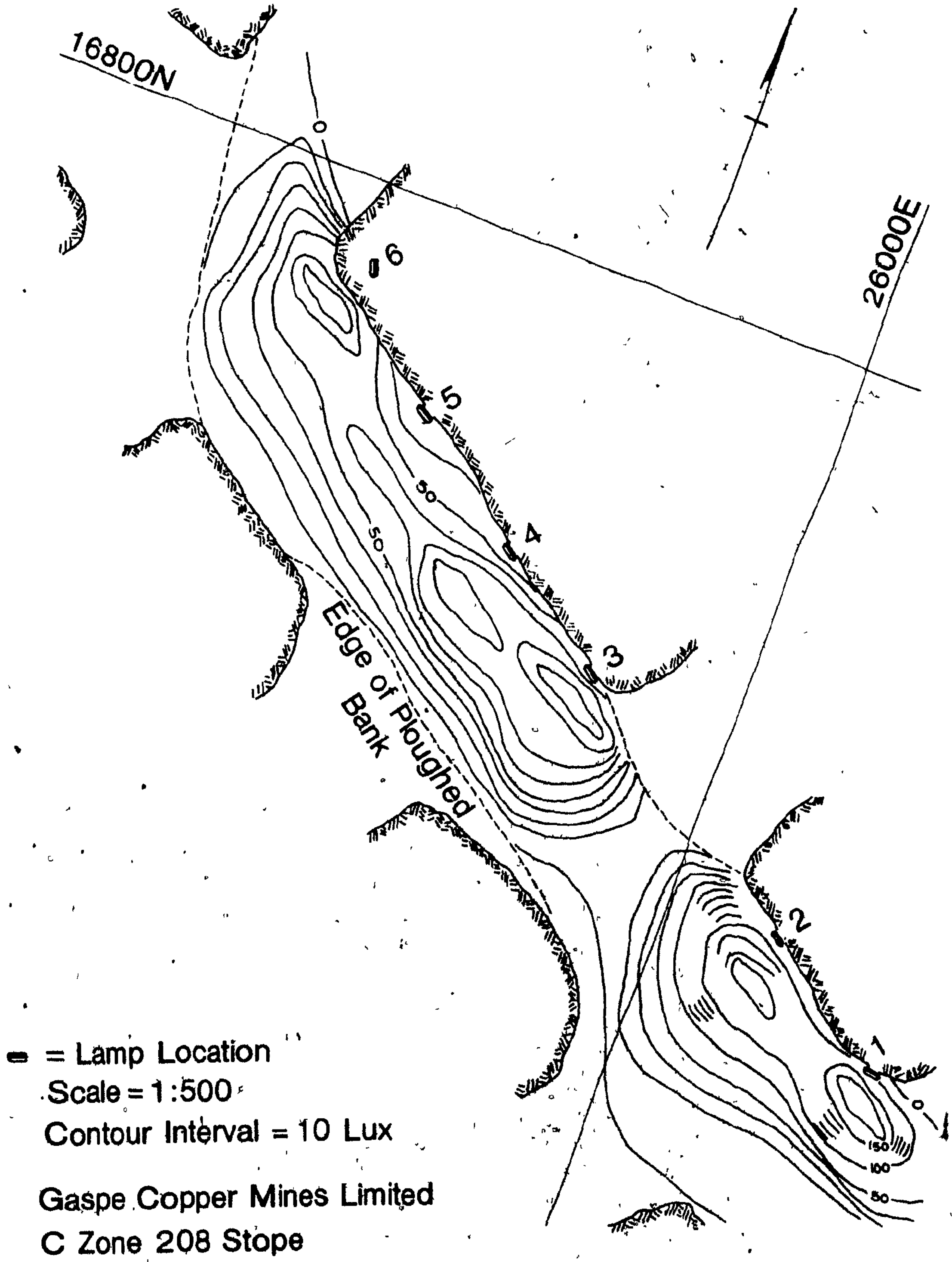
ILLUMINATION AND BRIGHTNESS MEASUREMENTS

8.1 General

Several articles are available describing methods of taking either illumination surveys or brightness surveys (13, 53, 54, 59, 80, 86, 101). This chapter describes basic measuring techniques as gleaned from the articles, gives an example of an illumination survey made by the writer, and tabulates illumination levels found in several underground working places in 15 Canadian mines.

There are two basic techniques by which the lighting level in a mine can be measured. Either the incident light in lx is measured in an illumination survey or the reflected light in asb is measured in a brightness survey (page 6). These surveys are done to determine how much of the light emitted by the source is actually being received where it is needed and to find how the light is being distributed. In some countries the mine lighting surveys are done to determine if certain required standards of light levels are being met. For this work incident light measurements are useless unless the reflectivity of the surface being measured is known. For this reason it is best to measure the reflected light directly.

The results are usually used to draw isolux curves for the measuring plane. Figure 37 on page 130 is an example



Sodium Lamp Isolux Plot
Figure 37

of an isolux plot. If incident light is measured the curves can be used to determine the total light flux from which an efficiency factor can be calculated. If reflected light is measured the plot could indicate if any areas of a working place fail to meet required standards and would be useful in redesigning a lighting installation.

8.2 Illumination by Incident Light Measurements

Three different recognized techniques can be employed depending on the purpose of the survey. These are:

(1) planar measurements

(2) separate measurements of diffuse and direct light

(3) maximum reading technique

8.2.1 Planar Measurements This method is used when the general level of illumination in the work place is required. Using a physical photometer the photocell is laid on the surface at each point at which the illumination is to be measured. The illumination level indicated by the microammeter is assumed to be the illumination on the surface at the point if accuracy is not required. Otherwise the errors inherent in physical photometry must be taken into account. These are described in Section 6.5 on page 78. Figure 8 on page 54 illustrates one method of taking a planar measurement.

8.2.2 Separate Measurements of Diffuse and Direct Light

This technique involves the separate determination of the quantity of light reaching the measuring point directly from the source, and the light reaching the same point after one or more reflections from the back and walls.

The illumination due to the direct light is measured by pointing the cell at the lamp and masking out all light from sources other than the lamp being considered. The reading obtained is then resolved normal to the surface where illumination is being measured. The indirect illumination is measured by placing the cell at the desired point on the surface and the reading then obtained is corrected by use of a calibration curve.

Roberts (7) describes the method. If the measurement of the direct light from the lamps plus the indirect light is called reading A, and if the total direct illumination found by summation from aiming at each lamp in turn is called B, then B is always less than A. A - B is the deflection due to indirect light and this deflection is then translated to its equivalent illumination by reference to an indirect light calibration curve of the type shown on page 84. The direct illumination, represented by B on the direct light curve, and the indirect illumination, represented by A - B on the indirect light curve, give total illumination when added together.

8.2.3 Maximum Reading Technique This technique is used when it is required to determine the manner in which light is being distributed from a fitting. The photocell is pointed at the light source. The reading is resolved normally to the plane being considered and the resolved component is assumed to be the illumination at the point of measurement. This procedure is repeated for several points from which isolux curves can be drawn to show the distribution of the light.

8.3 Brightness Measurements

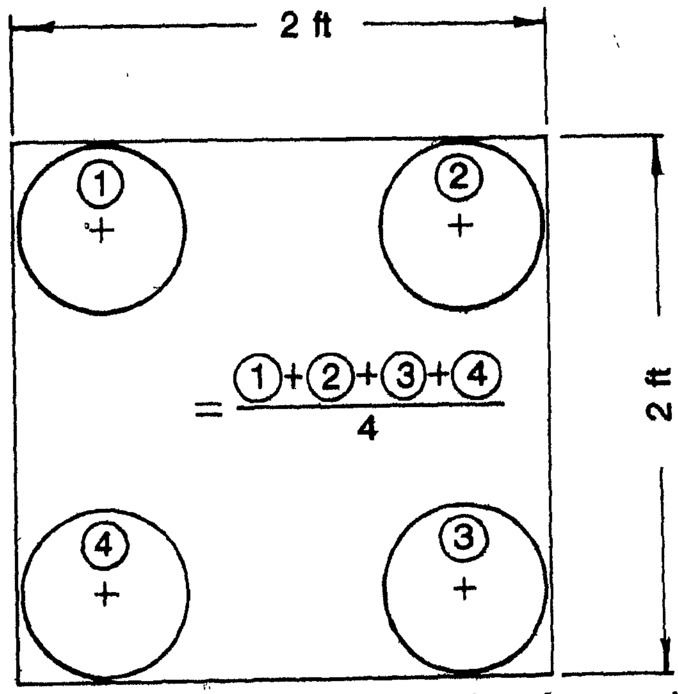
We see by reflected light rather than by incident light, so that this method of measurement is preferable if one is attempting to determine if certain standards or prescribed guidelines are being met. The method takes into account the actual reflectivity of the surfaces in the mine. Another advantage is that measurements can be carried out remote from the specific surface that is being measured.

On April 1, 1978, it will be required that all coal mines in the United States will need a minimum of 0.06 ft.L throughout the working place in any area where self-propelled mining equipment is being operated (109). Section 75.1719-3, in the Federal Register of April 1, 1976 informs the coal industry and equipment manufacturers of the methods to be used by the Mining Enforcement and Safety Administration (MESA) in determining compliance with the illumination standards. Because of the importance of this legislation, the MESA measuring technique is described.

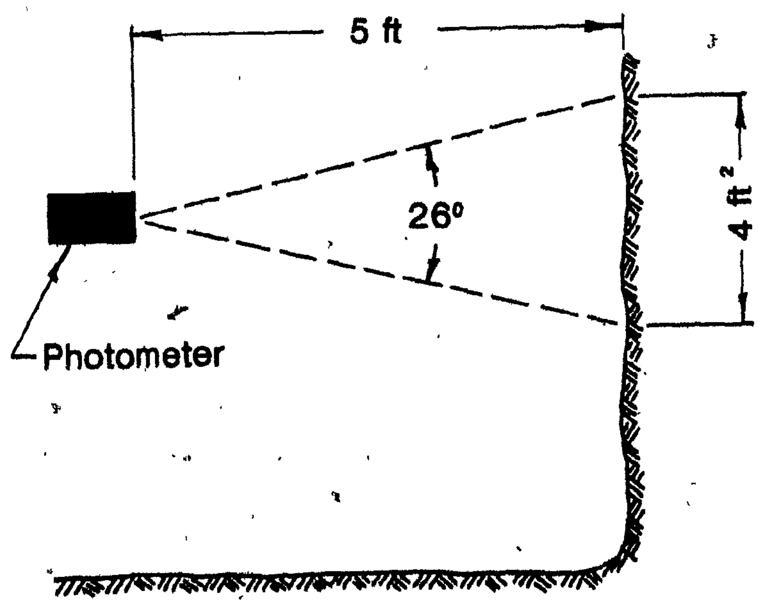
Reflected light will be measured. MESA enforcement personnel will probably use a "go/no-go" physical photometer that will display a green light if the brightness of a surface exceeds 0.06 ft.L, and a red light if the value is less than this minimum. Brightness measurements will be taken perpendicular to the surface being measured.

If measurements have to be taken close to a surface, that surface will be divided into square fields having an area not greater than 4 sq. ft. If actual values are being read, surface brightness for each square field will be considered as the average of four uniformly spaced measurements as illustrated in Figure 38. The area covered by each individual measurement is not to exceed 50 sq. in. With the go/no-go photometer a violation will be assumed to exist if the photometer displays a red light for each of the four measurements.

If no obstructions are present, measurements can be taken further back from the surface. One measurement is sufficient for determining compliance when the photometers used are designed to measure brightness of a round or square field having an area of not less than 3 or more than 5 sq. ft. The instrument used for this has a 26° acceptance angle and, when held perpendicular to the surface being measured



Determination of Brightness by Averaging
Figure 38



Geometry of a 26° Reflected Light Photometer
Figure 39

at a distance of 5 ft., will measure a round field of 4 sq. ft. The geometry of this reading is illustrated in Figure 39. Again measurements will be made perpendicular to the surface as the instrument is not cosine corrected.

8.4 Case Study

A recent lighting installation at Gaspe Copper Mines Limited has been picked as an example. Summer fogging conditions were prevalent on a ramp in one section of the mine. One-way haulage by 30 ton diesel trucks is employed on this ramp and the poor visibility creates a hazardous situation.

It was decided to use wall mounted luminaires to provide general lighting on the floor and on one wall. Backs are exceptionally high since the ramp is in a former stoping area. It was deemed not necessary to illuminate the back and not practical to illuminate the wall with the luminaires on them. A general brightness level exceeding 2.0 asb, measured in clear conditions was aimed at. This is about three times the value shortly to be legislated by the US Bureau of Mines but allowance had to be made for transmission losses. Dimensions of the roadway affected by fog were 10 m wide, 70 m long and 10 m high. Reflectivity of the wall and road surface was assumed to be 10%.

If the roadway is considered as a six-sided box, and it is desired to light half-way up the wall, then the surface area requiring illumination is

$$10 \times 70 + 5 \times 70 + 2(10 \times 5) = 1150 \ m^2$$

The lx needed to meet the 2.0 asb requirement is

$$2.0/0.10 = 20$$

Since a lumen is the amount of light equal to 1 lx evenly distributed over an area of 1 m^2, the total lumen requirement is

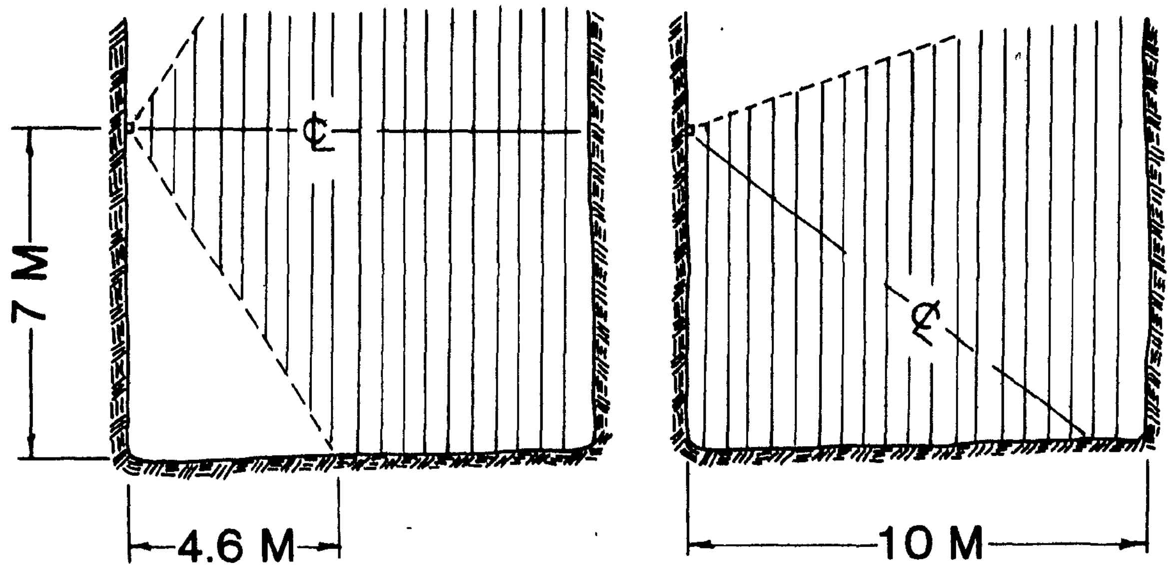
$$1150 \times 20 = 23\ 000$$

This would be the requirement if the light were distributed perfectly evenly. As the light distribution is far from uniform the total lumen figure must be multiplied by a factor dependent on the estimated losses from uneven distribution of light over all the surfaces and the distribution pattern of the luminaire itself. Methods of determining these factors are described in the literature (page 122).

Knowing the total lumens required and using manufacturers' tables of light efficiency in terms of lumens per watt, light distribution, and beam spread both horizontally and vertically; various lamp types, mounting heights, and spacings can be calculated in an attempt to determine the optimum arrangement.

After several trial calculations it was decided to use six 250W sodium vapour lamps mounted at a height of 7 m and spaced 13 m apart. Lamp beam spread from manufacturers' tables was 128^{o}H and 112^{o}V. To allow maximum illumination to fall on the roadway, lamp tilt was set at 35^{o}. Figure 40 illustrates the importance of the tilt angle on this type of luminaire and Figure 41 is a photograph of

Sodium Vapour Lamp Beam Spread = 128° H X 112° V

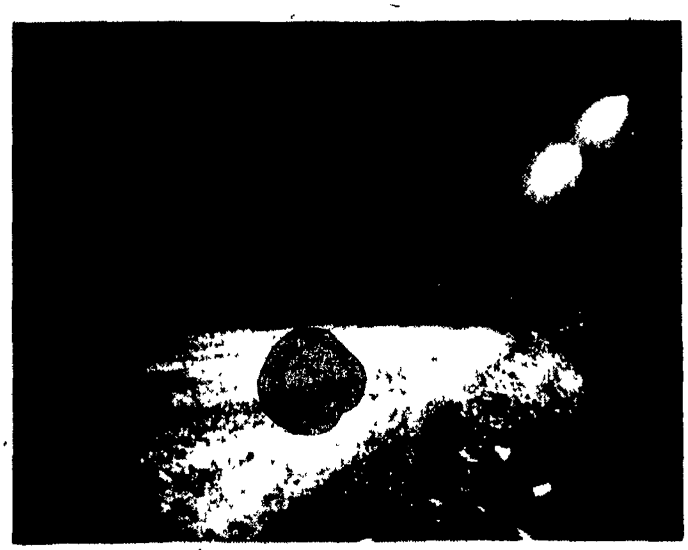


O Degree Lamp Tilt

35 Degree Lamp Tilt

Importance of Lamp Tilt Angle

Figure 40



Sodium Lamp Illumination

Figure 41

the ramp taken after the lights were installed. Photographs of the lights themselves are given on page 118.

An illumination survey was made after the lamps had been burning for at least 2 hours and is based on 56 planar measurements made over the field. Normal rules for contouring of a level survey were used to produce the isolux plot shown in Figure 37. At the time of the survey (December 1975) no fogging conditions were encountered and transmission losses were considered as nil.

An illumination survey is an important follow-up. In spite of careful calculations to determine the best choice of lamps, the performance of an installation can only be accurately assessed by actual testing after installation.

Some interesting points emerged from this survey. Light distribution is not even, with steep "hills" evident from the isolux plot. Since the pillars had been partly recovered and since the luminaires were mounted on the pillar walls, it was not possible to maintain the 13 m spacing between lamps. Since the eye is a poor judge of brightness the "hills" are not as noticeable in the field. To illustrate, in Figure 41 the writer is in the background a distance of 68 m away and is holding a 6 foot folding rule. The low area of illumination in the immediate foreground in the photograph corresponds to the low area of illumination between lamps 2 and 3 in Figure 37. The photograph was taken looking north-west and was shot beside lamp number 2. Uneven distribution of light is to be expected because of the uneven lamp spacing and is a natural consequence of the inverse-square law. It could be offset by staggered lights on both walls but this increases installation costs.

The reflected light emanating off the roadway was better than anticipated and in only a few places was lower than 2 asb. Several field measurements on the reflectivity of the roadbed gave an average of 0.12 in the 45^{o} recording position. The slightly higher reflectivity can partly account for the higher field luminance. Since this was a new installation, efficiencies would probably be higher than those used in calculations.

Brightness measurements on the south-east wall were much lower than expected and generally less than 0.1 asb. Accuracy suffered as readings were near the lower limit of the instrument range. Measurements of reflectivity indicated the reason. South-east pillar wall measurements gave values of 0.02 in the 45^{o} recording position. This is an extremely low value of reflectivity for a metal mine. All diesel exhaust gas is directed sideways onto this one wall only, because of the one-way haulage. Consequently, this wall is coated with fine carbon particles similar to lamp black in appearance and texture. This coating results in the low reflectivity values. In retrospect, it would have been better to mount the lights on this pillar wall and bathe

the other wall where measurements showed the reflectivity was four times higher. Reflectivity is still so low however that the floor can be considered to be lit by direct light only. The only advantage then would be a brighter wall.

The case study illustrates the importance of obtaining values for reflectivity before proceeding with calculations. In summary, since the estimated value of reflectivity for the floor in this example was close to the actual value, desired levels of brightness were obtained.

8.5 Illumination Levels in Canadian Mining

Measurements on the general level of illumination were made at a number of Canadian mines. Data are on file with the Department of Mining and Metallurgical Engineering, McGill University and are summarized in Appendix E on page 201. The following table gives some typical values.

TABLE 10

Typical Illumination Levels in Canadian Mines

Working Place	Illumination in lx
Shaft Station	5 - 60
Refuge Station	30 - 600
Haulageway	130 - 220
Garage	40 - 1100
Ramp	15 - 110
Crusher	10 - 200
C.&F. Stope	10 - 110
Fueling Station	70 - 430
Charging Station	10 - 60
Conveyorway	5 - 110
Underground Hoist Room	25 - 75
Shifters' Desk	70 - 1300
Shop Work Bench	130 - 1500

CHAPTER 9

REFLECTIVITY MEASUREMENTS

9.1 General

Good underground lighting design is not possible without a thorough knowledge of reflectivity. Not only do we see by reflected light but in an underground mine that portion of reflected light which does enter the eye is usually only a small percentage of the light which struck the object we are looking at. The majority of the light is absorbed by the surface. Measurements of this phenomena are necessary so that either the lighting installation can compensate for the loss or the surface can be modified to cut down on absorption.

In this report, reflectivity is defined as

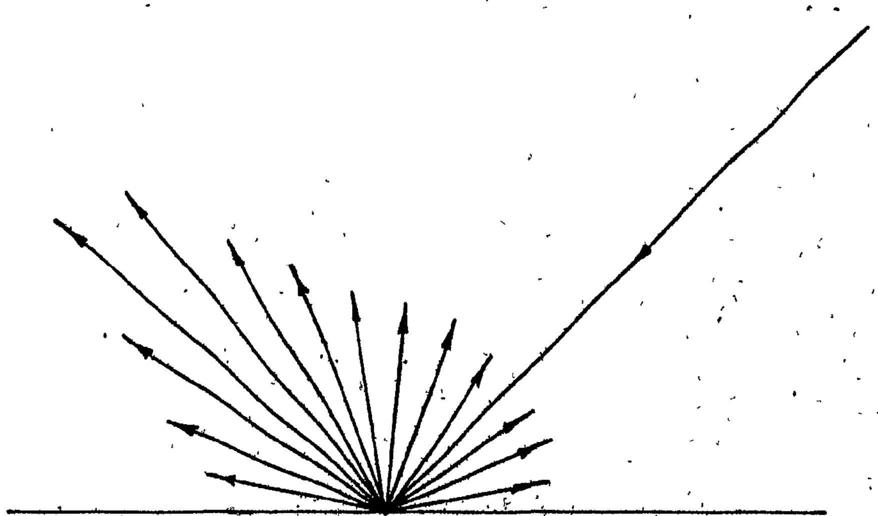
$$R = \frac{C \times R_s}{b}$$

where

R = reflectivity of surface being measured
c = mean instrument reading for the surface
R_s = assigned reflectivity of the standard used
b = mean instrument reading for the standard

Since the assigned reflectivity of the standard is a measure of the ratio of the reflected radiant flux to the incident flux, the value R then measures the efficiency of a surface in retransmitting light. If R = 1.00 then the surface reflects the same amount of light as the standard and if R = 0.00 all the light is absorbed.

In practice nearly all surfaces are a combination of diffuse and specular reflection. Slightly diffusing materials scatter the light only slightly, while highly diffusing materials scatter the light over a wide angle, having a reflectivity which can either vary over a considerable range of values or stay fairly constant. These surfaces appear light no matter from which direction they are viewed but their brightness can be greater when the viewing angle equals the angle of incidence. The phenomena is illustrated in Figure 42 with the arrows having a vector connotation.



Specular Diffuse Reflection

Figure 42

The figure is an oversimplification of what might actually be taking place since it shows only one ray of light incident onto the surface. A cone of light could strike the surface, or the incident light could be arriving from all directions. Similarly, one could attempt to measure the reflected light in only one direction, could measure a bundle of the reflected rays of light, or could measure all of the reflected light. This means there are three geometrical conditions for both the incident and collected fluxes; hemispherical, conical, and directional. Using the various combinations it is possible to have nine kinds of reflectivity measurements: (1) bi-hemispherical; (2) hemispherical-conical; (3) hemispherical-directional; (4) conical-hemispherical; (5) bi-conical; (6) conical-directional; (7) directional-hemispherical; (8) directional-conical; and (9) bi-directional.

Angles of incidence and of recording as well as the solid angles should be specified in any reflectivity measurement. If not specified then bi-hemispherical conditions are assumed. In this instance, all flux reflected in 2π steradians is included in the measurement. This can be measured with a sphere reflectometer, a receptor which is an integrating sphere having a flat circular aperture on which the test specimen is placed (78).

When specifying angles, the incident angle is given first, and then the recording angle. When the solid angles are not specified the assumption is made that they are infinitesimal which means the reflectivity would not change if they were made smaller. With textured surfaces the orientation of the surface may be important. A ribbed surface may have different reflectivities when the incident light strikes the surface along the axis of the ribs or at right angles to the ribs. Similarly a flat surface can give different reflectivities depending on the angle at which the surface is tilted. It is important to measure this tilt angle when the incident light path, the recorded light path, and the normal to the surface, do not all lie in the same plane. It is also important to specify the type of light that strikes the surface. With all other parameters held constant, reflectivity does not stay constant when the illuminating wavelength is varied.

9.2 Underground Reflectivity Measurements

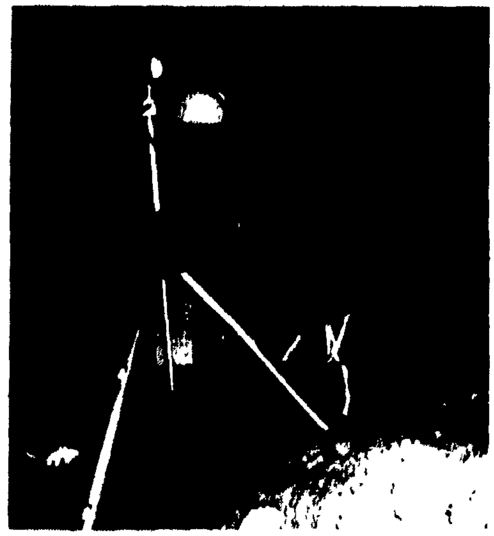
When possible specimens were gathered so that reflectivity measurements could be performed in the laboratory where conditions could be more accurately controlled. When it was not possible to remove a test surface or when it was felt that by removing the surface the light properties would be modified, measurements were conducted in the field. These included measurements on mining equipment, consolidated fill, and extremely dusty surfaces.

When the light source could be controlled geometric characteristics were made to coincide with C.I.E. standard conditions. "For the illuminator, illumination shall be within five degrees of, and centred about, a direction of 45 degrees from the perpendicular to the test surface. The area of the illuminated spot should be not less than that of a circle seven centimeters in diameter. Viewing should be within ± 5 degrees of, and centered about the perpendicular (78). Figure 43 shows a $45^{\circ}/0^{\circ}$ reading being taken on a wall and Figure 44 shows a $45^{\circ}/0^{\circ}$ reading being set up on a floor.

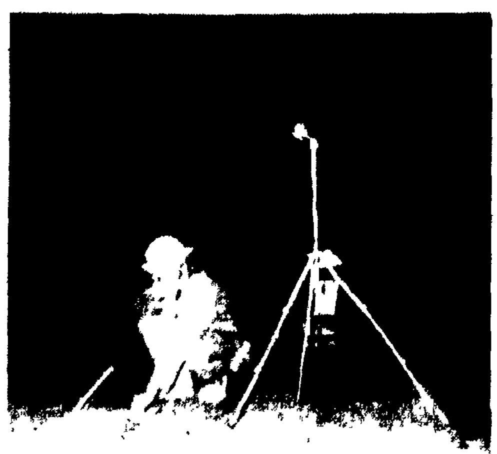
Since the measuring method chosen involved visual photometry the spectral energy distribution of the illuminator was made to coincide with the spectral energy distribution of the working standard lamp on the illuminometer for ease in luminance matching. The means by which this was achieved is described in Section 6.7.1. Observations were performed by a C.I.E. standard observer.

At times the light source could not be accurately controlled. This occurred when reflectivity measurements were made in well-lit areas. For example, measurements were made on the surface of a scooptram while it was inoperational and parked in an underground garage. The garage was well-lit and the walls were whitewashed to give a high reflectivity. It was assumed in this instance that the light source was diffuse. This is probably not a bad assumption in view of the domed shape of the ceiling, the garage then simulating a hemispherical reflectometer.

The basic reference standard for 45-degree, 0-degree reflectivity measurements using C.I.E. standard conditions is a pressed layer of freshly prepared magnesium oxide. It is assigned a reflectivity of 1.00 for the conditions of



45°/O° Wall Reflectivity
Figure 43



45°/O° Floor Reflectivity
Figure 44

45-degree illumination and perpendicular view. It is not convenient to use this standard underground because of preparation time and the large number that are required. Since the mine atmosphere is usually dusty fresh standards should be used for each reading. Fortunately secondary standards can be calibrated relative to the reference standard.

Various secondary standards have been used. Porcelain-enameled metal plaques are reasonably permanent in reflectivity and uniform over the surface. Hitchcock (99), in his work on reflectivity in underground coal mines, used "Millipore" Filter Paper #29325. This paper approaches a lambertian surface and has been compared to a magnesium oxide surface for every possible geometric condition of the reflectometer, (page 208). Unfortunately, at over $3.60 a sheet when bought in bulk the cost was prohibitive.

The secondary standard chosen for this study was a Kodak Neutral Test Card Cat 1527795, designed primarily for colour photography. The card has a grey side and a white side and the manufacturers claim an 18% reflectivity for the grey side and a 90% reflectivity for the white side. The grey side was chosen because of its cost, its guaranteed uniformity from card to card, and because its reflectivity more closely approximated the reflectivity of underground surfaces. This latter feature was important since brightness matches could be made quickly. Calibrations on the Kodak Grey Card were obtained from the National Research Council of Canada as shown in Table 11 (108).

TABLE 11

CALIBRATION OF KODAK GREY CARD FOR 2360K AND 2854K

SOURCE	GEOMETRY	REFLECTIVITY
2854K	$0^{o}/D$	0.178 ± 0.001
2360K	$0^{o}/45^{o}$	0.175 ± 0.002
2360K	$45^{o}/0^{o}$	0.179 ± 0.002

Envelopes containing four 8 in. X 10 in. cards were purchased for about $2.00. Each card was cut into 4 giving a secondary standard surface of about 20 in^2. These were then individually placed in plastic bags and sealed with scotch tape. Cards were fastened onto the surface to be measured by placing caulking compound from a gun and cartridge onto the white side and pressing the card firmly into place. Cards were destroyed after one use, since humidity, dust or dirt might affect their light absorbing properties.

Measurements were made with the MacBeth Illuminometer as described in Section 5.4.1 on page 57. Method of recording is shown on Table 20, page 209. Values of reflectivity are on file with the Dept. of Mining and Metallurgy, McGill University.

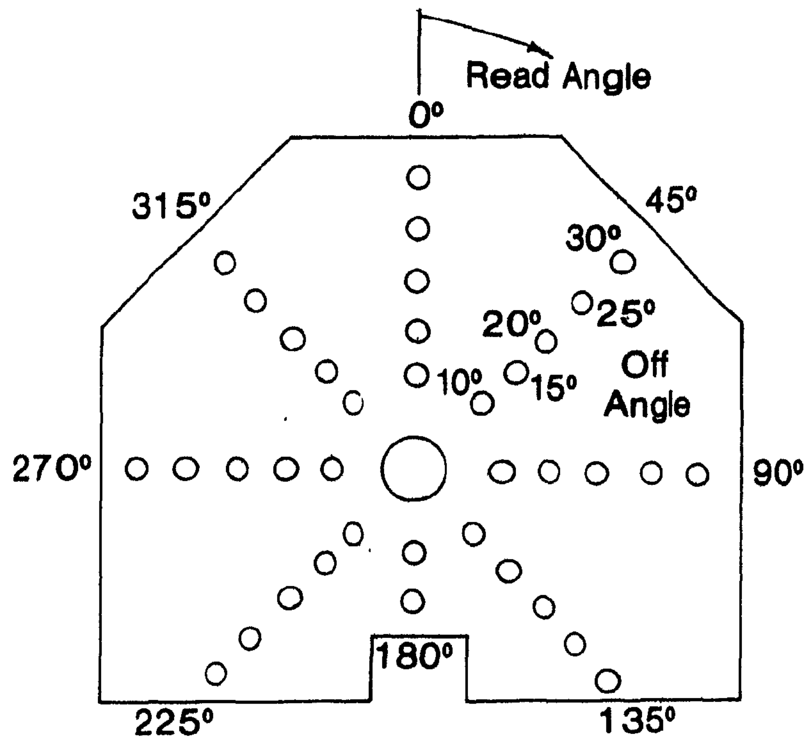
Precautions were taken to ensure both accuracy and precision. The rate of decay of the batteries was compensated for by adjusting the milliampere reading after each shot to bring it back to its standardized value.

9.3 Laboratory Reflectivity Measurements

Again the Kodak Grey Card was chosen as a secondary standard. Using a value of 0.179 in the $45^{\circ}/0^{\circ}$ position as base value, values of reflectivity were obtained for several possible geometric conditions (page 206). It then became possible to measure how the reflectivity of different surfaces varied with the incident angle and the viewing angle for bi-directional conditions. Since, however, there is an almost infinite number of geometric conditions, incident angle was generally held to 0°. Zero degree incidence is the most important angle since a cap-lamp, headlights on a jumbo, etc. are generally shone directly onto the surface to be viewed rather than obliquely.

The reflectometer used a modified miner's lamp diffused with ground glass as the light source. With modifications incorporated into the system and described in Section 5.4.1 it was not necessary to compensate for battery decay with time or for colour differences.

Readings were made with either a MacBeth Illuminometer or S.E.I. photometer mounted in a template as the detector. Figure 45 shows the geometry of the template which is positioned 1 m behind the sample. Figure 46 shows an operator sighting through the MacBeth Illuminometer mounted in one of the template holes and measuring the reflectivity of a rock sample mounted in the goniometer. The purpose of the template is to control the geometry of the recorded light.



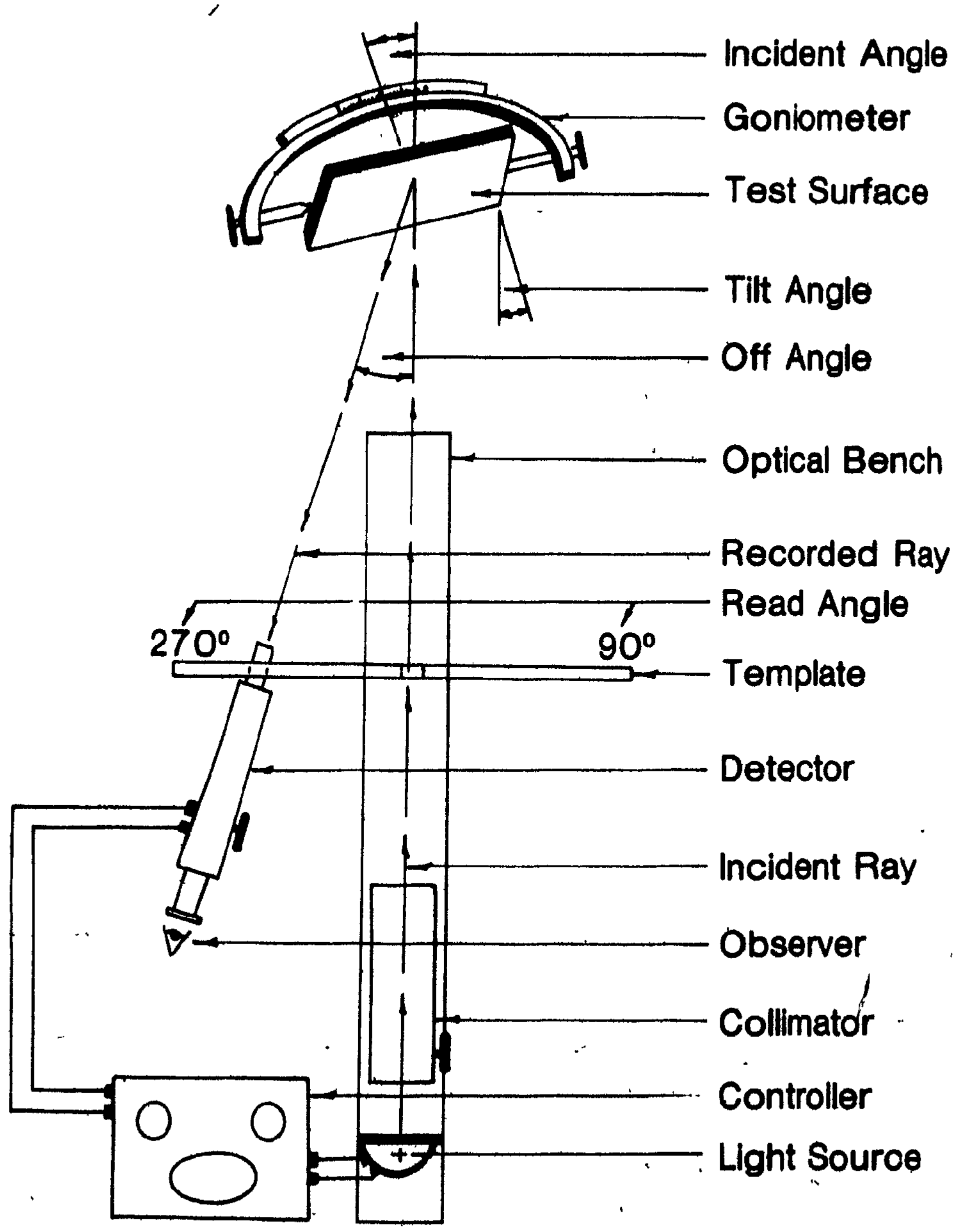
Template Geometry
Figure 45

Laboratory Measurement of Rock Reflectivity
Figure 46

The position of the detector is located with respect to the light source. This location is defined by the OFF ANGLE which signifies the angle between the detector and the light source, and the READ ANGLE which denotes the polar position of the detector around the light beam, with the 0^{o} position corresponding to the zenith. Azimuth angles are then read as one faces the specimen under study. Note that no off-angles of 20^{o}, 25^{o} or 30^{o} are possible at the 180^{o} read angle position because the optical bench occurred in these positions.

With test surfaces mounted on the goniometer the beam of incident light could be moved through a horizontal plane perpendicular to the surface measured. This is the INCIDENT ANGLE which was usually held to 0^{o}. The specimen could also be rotated about a vertical plane. This plane of adjustment of the light source could be varied with respect to the surface being measured when measuring a flat surface and was recorded as the TILT ANGLE. When measuring a non-ordered surface, the tilt becomes meaningless and was not recorded. The complete geometry of a bi-directional reflectivity measurement, as illustrated in Figure 47 , includes (1) incident angle, (2) off angle, (3) read angle, (4) tilt angle, and (5) colour temperature.

Reflectivity readings comprise the bulk of the experimental work and are presented in the appendix on page 210. A summary of the data is provided in Section 9.4.



Plan View of Bi-directional Reflectivity Measurement

Figure 47

9.4 Reflectivity Values

Table 12

Miscellaneous Surfaces

Surface	Range	Surface	Range
Backfill (dry rock)	0.25-0.30	Plastic (yellow lamp battery)	0.69-0.93
(sand)	0.10-0.18		
		Reflective tape	0.36-1.70
Cement (clean)	0.10-0.30		
(dirty)	0.05-0.13	Road (cement)	0.05-0.20
		(rockfill)	0.08-0.11
Gunite (clean)	0.20-0.33	(sandfill)	0.10-0.18
(dirty)	0.08-0.13		
		Rubber (tire)	0.02-0.05
Metal (clean)	0.04-0.27	(boots)	0.04-0.18
(rusty)	0.04-0.18		
Paint (hard hat white)	0.85-1.09	Shotcrete (clean)	0.36-0.50
(hard hat brown)	0.06-0.12	Timber (sawn)	0.35-0.53
(vehicle fresh)	0.02-0.59	(bark)	0.07-0.17
(vehicle oily)	0.02-0.30		
(wall fresh)	0.36-0.60	Whitewash (fresh)	0.65-0.95
		(dirty or faded)	0.20-0.60

Table 13
Ore Surfaces

Surface	Range
Chalcopyrite (fresh)	0.32-0.70
(oxidized)	0.08-0.24
Galena	
Gypsum	0.45-0.65
Magnesite	0.85-0.90
Pent-Pyrrho (fresh)	0.12-0.75
(oxidized)	0.08-0.28
Pyrite	0.20-0.34
Sphalerite	0.06-0.22
Talc (white)	0.57-0.81
(grey)	0.27-0.41

Table 14
Rock Surfaces

Surface	Range
Biotite gneiss	0.15-0.21
Biotite schist	0.10-0.42
Calcareous siltstone	0.47-0.63
Chlorite schist	0.05-0.41
Diorite	0.10-0.15
Gabbro	0.08-0.12
Limestone	0.35-0.55
Norite	0.06-0.15
Pegmatite	0.24-0.27
Quartz (grey)	0.36-0.52
Quartz Diorite	0.10-0.33
Sericite schist	0.27-0.30
Serpentine	0.13-0.46
Shale	0.25-0.45
Slate	0.16-0.34
Ultramafic	0.06-0.12

9.5 Increasing the Reflectivity of Mine Surfaces

The added luminance in mines which can be obtained by the simple expedient of increasing the reflectivity of a surface should not be overlooked. This is particularly true for floors, walls and backs of the underground openings since these are the largest reflecting surfaces. The effect of a fresh coat of whitewash is striking. The greatly improved reflectivity of the whitewashed back or walls has to be measured to be appreciated. Reflectivity measurements on both the untreated wall and the same wall with whitewash on it were obtained at three mines where the whitewash was at least two years old.

Effects of Whitewash on Surfaces

Mine	Untreated Surface	Whitewashed Surface
Brunswick	0.25 - 0.30	0.40 - 0.60
Strathcona	0.25 - 0.32	0.35 - 0.70
Flin Flon	0.13 - 0.20	0.25 - 0.70

Reflectivities are roughly twice as high for a whitewashed surface than for the untreated surface. For fresh whitewash, values range from 0.70 to 0.95. Whitewashing then can easily double the luminance without altering the light source. Areas noted where whitewashing has been applied include shaft stations, main haulageways, lunch rooms, ramps, underground garages, tipples, crusher stations, internal hoist rooms and conveyor ways.

Other rock surface coatings are equally effective. Stone dust might prove beneficial in stoping areas. Although not nearly as permanent as whitewash it is much easier to apply (75). Paints too have proven satisfactory. Metallic paints though should be avoided. Not only is their reflectivity not as high but it has a high specular component as well. A flat white paint would be best. Its reflectivity is similar to fresh whitewash but is more expensive. Any treated surface other than stone dust should be washed periodically as accumulations of dust or mud lower the reflectivity with time.

In addition to cutting down on tire wear a cement floor can greatly improve illumination since the reflectivity of cement is often higher than the country rock. Similarly shotcreting or guniting can modify the reflective properties as well as provide ground support.

Specifications for new equipment could include a minimum value for reflectivity. The writer took measurements on a new stoper painted a metallic grey with a value of only 0.08. Yet values over 0.50 are possible with many metal paints. In the initial draft proposed by MESA for rules governing illumination in mines a minimum reflectivity of 0.50 was specified. However, the new regulation states that paint used on exterior surfaces of mining machines shall have a minimum reflectivity of 0.30, except cab interiors and other surfaces which might adversely affect visibility (116). The change was instituted in order to permit the use of common types of readily available protective paints and materials.

To a certain extent, the reflectivity can be controlled by choice of light source. Mercury vapour emissions, which are in the blue green band, tend to give high reflectivity factors, whereas sodium vapour emissions, which is monochromatic light in the yellow band, have a large part of their light absorbed.

The use of reflective tape is highly recommended. Laboratory measurements on various types of tape gave reflectivity values ranging from 0.90 to over 1.00 at 0^{o} incident and low viewing angles. The tape is often installed on bicycles. When driving at night the brightness of the tape provides an effective visible warning of the presence of the cyclist. Underground the tape would be installed on each end of mining machines and on the sides and back of a hard hat. Reflective tape will soon be mandatory in the United States on machines and hard hats. MESA rules specify that the area of each tape shall be not less than 10 square inches when mounted on machinery and 6 square inches when placed on a hard hat (116).

If properly used and maintained, dark red glass reflectors are superior to trip lights on running equipment in lighted haulageways (51,105).

CHAPTER 10

A CODE FOR MINE LIGHTING

10.1 General

Good lighting is necessary for safe and efficient work in underground mines. The provision of codes and recommendations would be an invaluable guide to the person planning the underground lighting and would avoid designing from first principles. Any code so produced must be very carefully arrived at and standards set must be both economically feasible and socially desirable. It must be borne in mind that any code is rarely the complete answer to the problem it was meant to help solve, for whenever a stage of knowledge is reached upon which a code is based, unsolved problems still remain.

In Canada, each province regulates its own mines act. Most provinces follow Ontario's lead since this province was the first to come out with regulations and has maintained a high level of research. Where regulations exist concerning lighting in mines, the provinces usually follow the recommendations of the Canadian Electrical Code. Part V of the Code 'Use of Electricity in Mines' states that lighting circuits shall be provided with protection and control in accordance with the requirements of the Canadian Electrical Code Part I 'Essential Requirements and Minimum Standards Governing Electrical Installations for Buildings, Structures and Premises.'

Hence, the means of setting up the lighting is well regulated but no definite requirements for illumination levels have yet been made. Illumination levels presently used in mines are below the levels of easy measurements and outside any recognized standard of illumination. This is largely because of economic considerations. A certain minimum standard of lighting should be aimed at. What this standard should be, however, is of a controversial nature, and guidance can only be obtained by referring to lighting installations in mines in other countries and in other industries.

Several countries have published guidelines on the quantity and quality of light that shall be required for various underground tasks. Canada has access to this information and how it was arrived at through its membership in the Commission International de l'Eclairage (CIE). This is an international body concerned with illumination which holds meetings at 4-year intervals. Dr. Gunter Wyscecki of the Physics Division, NRC is Vice-President of this international body. All countries having an interest in lighting matters send delegates to the CIE. Recent meetings have been:-

15th	1963	Vienna
16th	1967	Washington
17th	1971	Barcelona
18th	1975	London

The 19th session is slated for Japan in 1979.

Committee S-3.1.5 - 'Mine Lighting' formerly covered illumination in mines. For each meeting, one country was selected to act as secretariat country for mine lighting.

This country circulated a questionnaire to member countries and a summary was prepared for discussion at the CIE meetings. Unfortunately only about half the member countries replied to the questionnaire, and in consequence in 1967 it was decided to disband the committee. At the London conference it was decided to reactivate the committee on Mine Lighting and it is now known as Committee 4.10. Canada's affiliation to the C.I.E. is through the Canadian National Committee of the International Commission on Illumination (CNC/CIE). Secretary of CNC/CIE at the time of writing is

Mr. Alan Robertson
Division of Physics
National Research Council
Ottawa, Ontario
K1A 0R6

Mr. G.K. Brown of Fuels Division, Mines Branch has in past years collected available information on mine lighting in Canadian mines. The present Canadian corresponding member for mine lighting is Mr. Fred Doward of Edmonton Consulting.

Information on lighting in Canadian mines prior to 1967 can be found in the various CIE reports on mine lighting (113,114).

10.2 Mine Lighting in Other Countries

The following data is a summary of regulations or guidelines pertaining to the level of illumination required in underground working places in five other countries. Since standards of illumination tend to increase from time to time there is no guarantee that the data presented is up to date.

10.2.1 Great Britain The National Illumination Committee of Great Britain divided the subject of lighting into eight sections. The lighting of mines is a sub-section of the main section titled "Applications - General". This sub-committee has reported that the standard of lighting underground is too low and reacts adversely on production, safety and health, and came to the conclusion that it was anomalous that standards for general industry should be any less than that in mines. The minimum level of working areas in general industry is 6 f.c. (113).

The committee urged that a minimum standard of lighting of 0.4 f.c. in the general working area should be aimed at and no attempt was made to establish different illumination standards to apply at different places. Since this standard of lighting is not likely to be provided by portable lamps alone, a system of cable fed lamps supplemented by cap lamps is probably necessary.

Currently, there is no code but guidelines are suggested, based on standards employed by the London Underground Transport System. These guidelines state that illumination should vary with the task (39).

A level of illumination of not less than 0.5 f.c. on the working plane along haulage roads should be aimed at, while at points where specific work is being carried out this minimum must be considerably increased to something of the order of 6.0 f.c. for workshops. Main junctions, loading and transfer points should be illuminated to a level of at least 3 f.c. Such light quantities, however, must be accompanied by good non-glare lighting installations.

10.2.2 Hungary Table 15 shows the values of illumination recommended in Hungarian mines (38), and are the highest lighting levels found in Europe.

Table 15

Recommended Lighting Levels in Hungarian Mines

Working Place	Illumination Level (lux)
Lowest Point of Shaft-High Traffic	60 - 100
Low Traffic	40 - 60
Haulageways - High Traffic	5 - 10
Low Traffic	2 - 4
Intersections	40 - 60
Loading Points	40 - 60
Around Machinery	20 - 50
Underground Repair Room	20 - 50
Transfer Points	10 - 50

10.2.3 Germany and Holland A report entitled "Safety Aspects of Mining Methods in Germany and Holland" states that on the coal-face an illumination of 0.5 f.c. is usually exceeded and is generally nearly 10 f.c.; some faces having about 20 f.c. (114).

The standards of the German Technical Advisory Lighting Association make an attempt to establish different illumination standards at different places but no attempt was made to specify the luminance desired off the working plane.

10.2.4 Switzerland In Switzerland the values given in Table 16 are generally applied regardless of the industry and are for general guidance only.

Table 16

Swiss Guide to Light Intensities (1)

Type of Work	Examples	Necessary Light Intensity in lux
Not precise	Storing of goods	80 - 170
Moderately precise	Fitting (not precise)	170 - 350
Precise	Reading, Drawing	350 - 700
Great Precision	Fitting (precise)	700 - 10 000

10.2.5 United States In the United States a great deal of detailed study has been done to provide supporting data for proposed standards in coal mine illumination. This is in response to the requirements of the Coal Mines Health and Safety Act of 1969 (116), which required the Secretary of the Interior to propose standards under which all places in a mine are to be illuminated while persons are working. The necessary research to provide basic data for establishing light standards was conducted by the National Bureau of Standards and sponsored by the Bureau of Mines.

Hitchcock (99), Halldane (98) and Yantz (110) all conducted important investigations. Hitchcock defined the visual tasks involved in the underground mining operation, used a visual task evaluator and mock up of mining machinery to determine the minimum luminance levels for each of these tasks, and applied corrections for age and other environmental considerations. For this work he used techniques developed by Blackwell (17,20,21,22). Halldane reported on maximum levels of illumination which should be permitted and methods of eliminating glare. Yantz investigated available mine lighting hardware and reported on hardware which had been developed specifically to comply with proposed standards.

Using guidelines that 20 ft.L. constitute glare conditions underground and 0.06 ft.L. represents the minimum light for a person to distinguish an object, standards were proposed by MESA which covered illumination levels, light distribution, reflectivity of equipment, cut-off angles, and method of measurement. These standards were published in 1970 and modified in 1971. A public hearing was conducted, and revised standards were published in the Federal Register of April 1, 1976. In the April 1 issue notice was given that the final standards will be published in the Federal Register of October 1, 1976 and eighteen months after this date all working places in a mine shall be illuminated in accordance with these standards.

Section 75. 1719-1 of the April 1 issue of the Federal Register is quoted in part. "Each operator of an underground coal mine shall provide each working place in a mine with lighting as prescribed while self-propelled mining equipment is operated in the working place. Self propelled mining equipment means equipment which possesses the capability of moving itself or its associated components from one location to another by electric, hydraulic, pneumatic, or mechanical power supplied by a source located on the machine or transmitted to the machine by cables, ropes, or chains. The lighting prescribed shall be in addition to that provided by personal cap lamps. The luminous intensity (surface brightness) of surfaces that are in a miner's normal field of vision of areas in working places that are required to be lighted shall be not less than 0.06 foot-Lamberts."

Although the standards call for a minimum of 0.06 ft.L which, on first reflection, seems like a very low level, it should be borne in mine that the entire area is to be illuminated. The peripheral vision is thus recognized as being important for the safe performance of underground mining tasks (page 17).

The maintainance of a minimum level also ensures men will not have adaption problems as they leave the illuminated work place since 0.06 ft.L. is about the same level of light as that provided by the cap lamps for close visual tasks. When leaving an illuminated face area all the miner suffers is a loss in peripheral vision.

Hitchcock's work showed some tasks require luminances greater than 0.06 ft.L. Since these tasks are all relatively close to the operator they all receive supplemental illumination from the cap lamp so again there is justification for the 0.06 ft.L. minimum. The usual cap lamp produces a luminance level of around 0.1 ft.L. for close tasks (56). Since these cap lamps have beam angles that range from 5^{o} to 32^{o} it does not provide adequate lighting to the sides. A special cap lamp (page 110) has been developed for this purpose (28,93).

The United States has taken an important first step in regulating mine illumination and in developing the necessary hardware in spite of the inherent costs to the coal industry. Their continuing investigations and research will be followed closely. It will be interesting to see if the code is modified in the final draft and if it is eventually applied to the rest of the mining industry.

10.3 A Mine Lighting Code for Canada

Work by Weston (66) and Blackwell (20) in particular, have shown that it is possible to derive a lighting code on a strictly analytical and scientific basis, thus avoiding the criticism of commercial pressure. Blackwell's data was adopted by the CIE in Washington in 1967 and is universally known. The 0.06 ft.L. level used in the United States was arrived at by using a Visual Task Evaluator (88) developed by Blackwell. Laboratory experiments simulated both the coal mine environment and the working tasks to arrive at illumination levels. The experiments could be repeated in any country based on that country's mining tasks, mining environment, and mining equipment to analytically arrive at a minimum luminance level.

Basically there are two distinct methods by which recommended levels of illumination can be specified for any given visual task. An absolute minimum illumination can be stated in which the visual task can be performed adequately. In American coal mines if the level of luminance falls below 0.06 ft.L. where mining machinery is employed, fines can be imposed. While this will undoubtedly lead to an increase in illumination it has the major disadvantage that operators will attempt to just get above the minimum to keep costs down. Also, where minimum standards have been set, many authorities consider that the figures are too low.

The second method of specification is to use a recommended level which is considerably above the obligatory minimum. Codes of recommended lighting practice usually state both the necessary illumination level for adequate visual performance and the level which will avoid glare discomfort. Comparisons between different codes issued in different countries show that universal agreement is difficult to obtain.

As the mechanized equipment used in modern mining becomes more sophisticated and more costly it is increasingly important that the level of illumination should enable men to work safely and efficiently in and around machines. Mine operators will pay increasingly close attention to well thought out lighting specifications. Recommendations should be spelled out in the Mining Act to meet this need for guidelines.

A third method is offered as to how these specifications could be spelled out. Hitchcock has shown how the minimum level of mine lighting can be arrived at. Other experimenters (44,66) have shown that the performance of working men increases with illumination up to a certain level of lighting and once this level is reached further illumination will have no beneficial effect on working performance. Experimental work simulating mining conditions could determine what this maximum level of illumination is. Guidelines could then be published for various mining tasks listing the range of values between minimum and maximum. This would allow operators to strike a balance between costs and benefits. As data accumulates it should be possible to narrow the recommended range.

At the same time formulae could be given to equate any illumination value in the given range to the allowable maximum brightness of the source and to the maximum allowable change in illumination with changing locale. This would then control glare and eliminate eye adaptation problems.

CHAPTER 11

CONCLUSION

Underground lighting can be greatly improved over that provided by vehicle headlights or cap lamps. Some of the necessary hardware is making its appearance on the market, its benefits have been field tested, and the value and means of improving reflectivity are now understood.

Mine operators and mine light designers should be aware of this technology. It is important too that they understand the consequences of the quantity and quality of underground illumination since it has implications in the areas of worker productivity, worker safety, worker morale, and equipment accidents. With this understanding, installation and operating costs for mine illumination can be justified.

Tables of illumination values encountered at several underground work sites are provided in Appendix E. Generally speaking, where fixed lighting was employed, values were well above any recommended minimum. The variety of lighting hardware encountered by the writer and described in Chapter 7 demonstrates too that Canada is in the forefront in innovative practices. The number of mines though that are taking positive action to improve the mine luminance environment still remains in the minority.

Tables of reflectivity values are provided in Appendix H for several types of surfaces commonly encountered in underground workings. This data is important for several reasons and provides the first extensive measurements of its kind applicable to Canadian mining practices. In general the reflectivity values of natural surfaces are very low, pointing out the importance of measuring light in terms of luminance rather than illuminance. The tables allow the mine lighting designer to compensate for the light naturally absorbed by the underground surfaces with which he is dealing. Finally, if optimum luminance levels are to be determined experimentally, then the mine environment will have to be duplicated in the laboratory. The predetermined reflectivity values will allow the experimenter to simulate underground surfaces in a laboratory environment where precise measurements can be taken.

Since one sees by reflected light then this light should be used in almost all design criteria. The direct light from source to eye retains its importance only when dealing with the effects of glare. Although a great deal of research has been done to establish what constitutes glare and how best to avoid it, research is badly needed to determine what the optimum luminance level is for various underground tasks. Mining acts should specify minimum and maximum luminance levels for tasks. These standards of luminance could act as recommendations and need not necessarily be made mandatory. The research techniques have been developed to provide these values and their publication in the mining act would give them the necessary stamp of authority.

The environmental aspect of underground mine lighting is an excellent field for other research. In addition to the establishment of luminance standards, other areas requiring investigation are:

- the development, testing, and ultimate government sanction of an inexpensive photometer to measure low levels of luminance.
- the correlation which exists between worker production and the quantity and quality of light in the working place.
- the effect of light on accident frequency and severity to men and equipment.
- the development and testing of small battery powered light sources to replace the traditional tungsten filament in the miner's cap lamp.
- the testing of monochromatic sources of light to ascertain the benefits which might be gained because of increased visual acuity and decreased light transmission losses.
- the development of a simple field procedure to measure reflectivities of surfaces underground,

thereby enabling mine environmental engineers to obtain basic data needed in lighting design calculations.

- the investigation of the effects of the various parameters affecting underground illumination so that suitable design formulae can be arrived at.
- the testing of various types of metal paints to ascertain those most suitable for equipment identification.
- the testing of inexpensive rock surface coverings to ascertain those most likely to give high reflectivity with a low specular component.
- the testing of surface coatings to find those that compare in reflectivity to underground rock surfaces so that underground visual tasks can be simulated in a photometric laboratory.
- a continuation of the development and testing of mine illumination hardware to find higher efficiency, lower brightness, longer lasting, and less expensive AC and DC light sources.

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APPENDIX A

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APPENDIX B

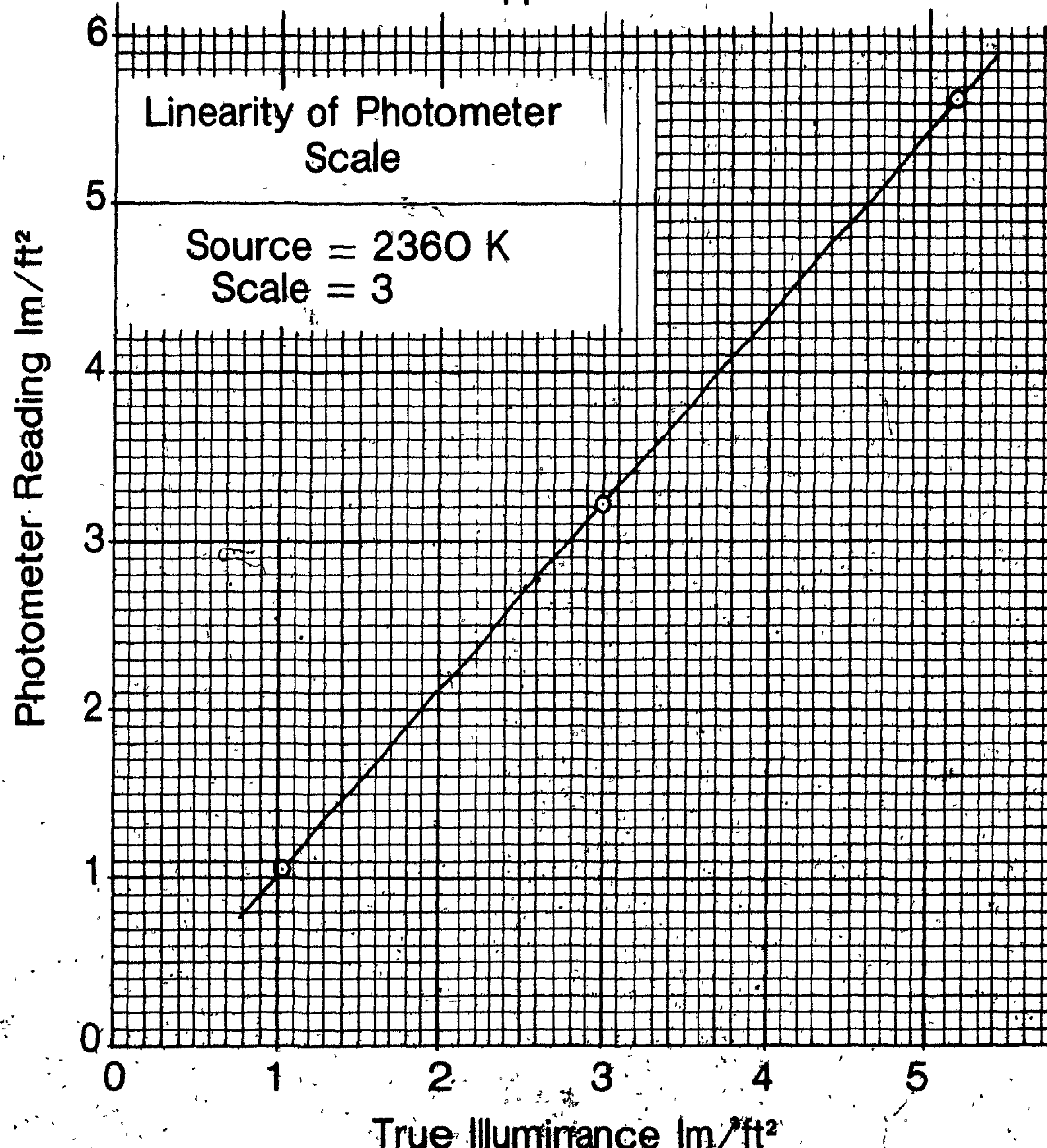
DETERMINING SI UNITS BY TABLE

The table is found to be easier and faster to use than to multiply by the appropriate conversion factor. For example, to determine the lux equivalent of 350 foot candles, 350 is located in the first column and the value 3766 is found on the same line in the second column under lx. This value would then be rounded off to three significant figures. If 35 or 3.5 foot-candles are to be converted, the 350 foot candle value would still be used, the value being decreased by a factor of 10 or 100(42).

TABLE 17

ft.L f.c	lx	$\frac{cd}{m^2}$	ft.L f.c	lx	$\frac{cd}{m^2}$	ft.L f.c	lx	$\frac{cd}{m^2}$	ft.L f.c	lx	$\frac{cd}{m^2}$
100	1076	343	330	3551	1131	560	6026	1919	790	8500	2702
110	1184	377	340	3658	1165	570	6133	1953	800	8608	2741
120	1291	411	350	3766	1199	580	6241	1987	810	8716	2775
130	1399	445	360	3874	1233	590	6348	2021	820	8823	2809
140	1506	480	370	3981	1268	600	6456	2056	830	8931	2844
150	1614	514	380	4089	1302	610	6564	2090	840	9038	2878
160	1722	548	390	4196	1336	620	6671	2124	850	9146	2912
170	1829	582	400	4304	1370	630	6779	2158	860	9254	2946
180	1937	617	410	4412	1405	640	6886	2193	870	9361	2981
190	2044	651	420	4519	1439	650	6994	2227	880	9469	3015
200	2152	685	430	4627	1473	660	7102	2261	890	9576	3049
210	2260	719	440	4734	1507	670	7209	2295	900	9684	3083
220	2367	754	450	4842	1542	680	7317	2330	910	9792	3118
230	2475	788	460	4950	1576	690	7424	2364	920	9899	3152
240	2582	822	470	5057	1610	700	7532	2398	930	10010	3186
250	2690	857	480	5165	1644	710	7640	2432	940	10110	3220
260	2798	891	490	5272	1679	720	7747	2467	950	10220	3255
270	2905	925	500	5380	1713	730	7855	2501	960	10330	3289
280	3013	959	510	5488	1747	740	7962	2535	970	10440	3323
290	3120	994	520	5595	1782	750	8070	2570	980	10540	3357
300	3228	1028	530	5703	1816	760	8178	2604	990	10650	3392
310	3336	1062	540	5810	1850	770	8285	2638			
320	3443	1096	550	5918	1884	780	8393	2672			

Appendix C



Calibration of EEL Photoelectric Photometer

Figure 48

Appendix D

Table 18

List of Participating Mines
Underground Lighting Studies

Mine No.	Mine Name	Products Mined	Company	Location
1	Kilmar	magnesite	Dresser Industries Canada Ltd.	Quebec
2	Baker	talc	Baker Talc Limited	Quebec
3	Bathurst	lead zinc copper silver	Brunswick Mining & Smelting Corp. Ltd.	N.B.
4	Needle Mountain	copper molybdenite	Gaspé Copper Mines Ltd.	Quebec
5	Falconbridge	nickel copper	Falconbridge Nickel Mines Ltd.	Ontario
6	Strathcona	nickel copper	Falconbridge Nickel Mines Ltd.	Ontario
7	Creighton	nickel copper	Inco Limited	Ontario
8	Stobie	nickel copper	Inco Limited	Ontario
9	Denison	uranium	Denison Mines Ltd.	Ontario
10	New Quirke	uranium	Rio Algom Ltd.	Ontario
11	South Main	copper zinc gold silver	Hudson Bay Mining & Smelting Co. Ltd.	Manitoba
12	Schist Lake	copper zinc silver	Hudson Bay Mining & Smelting Co. Ltd.	Manitoba
13	Manibridge	nickel copper	Falconbridge Nickel Mines Ltd.	Manitoba
14	Thompson Tl	nickel copper	Inco Limited	Manitoba
15	Birchtree	nickel copper	Inco Limited	Manitoba

Appendix E

Table 19

Fixed Installation Illumination Levels in some Canadian Mines

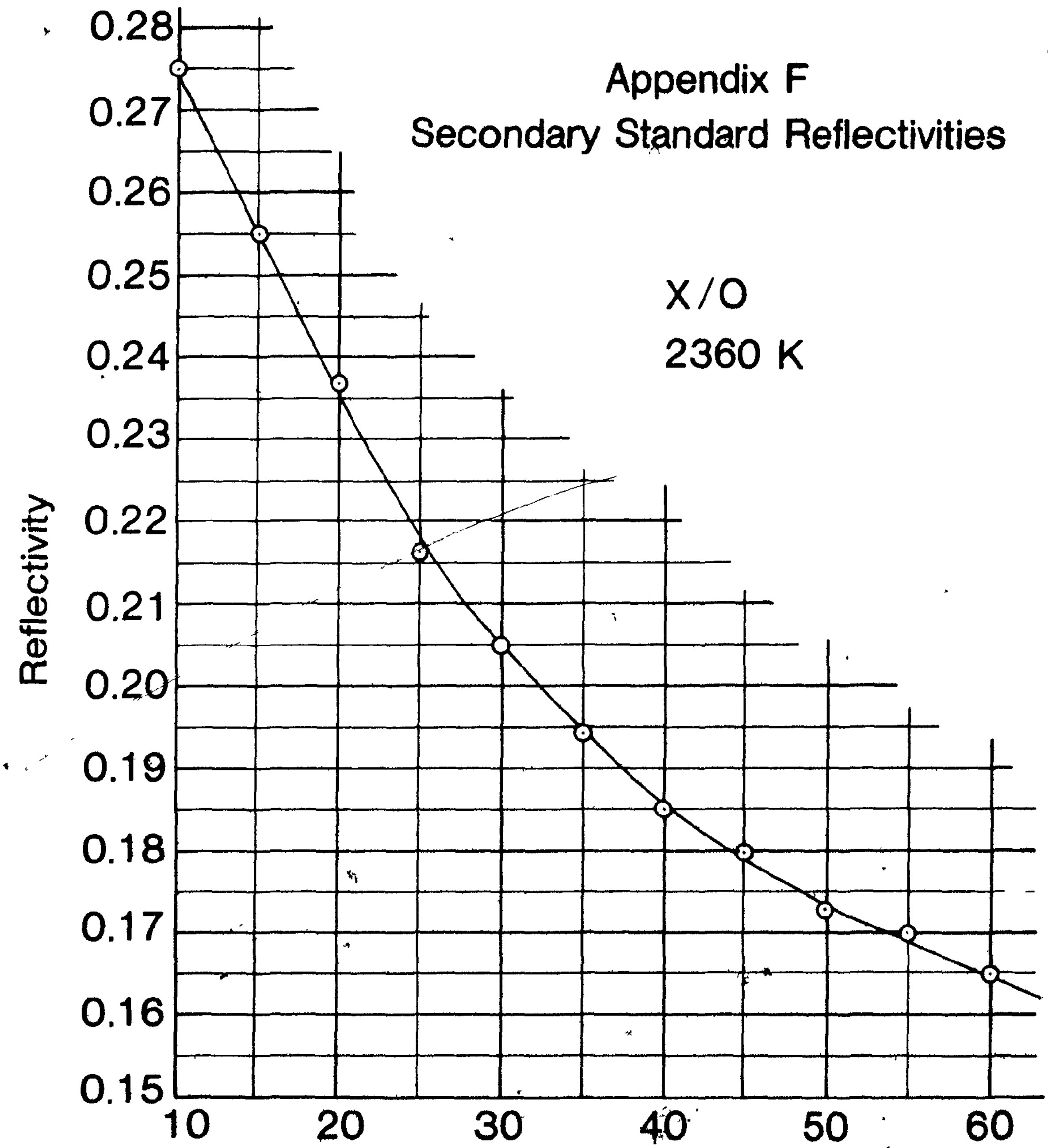
Underground Working Place	Mine and Location	Type of Light Source	Description	Highest Value (lx)	Lowest Value (lx)	Mean Value (lx)
Shaft Station	#2 400 L. at fire door (floor)	100W t. fil. Verd-a-Ray	single bulb protective cover 2m ht.	8.4	4.2	8.0
	#5 2800 L. (floor)	200W t. fil. G.E. 1000 h	2 bulbs	85	45	65
	#6 2925L.	100W t. fil. Rough Service	bulbs strung on cable at 3m intervals	34	4.3	33
Grizzly	#2 400 L. ore pass (floor)	100W t. fil. Verd-a-Ray	single bulb 2.5m ht.	14	12	13
C & F Stope	#14 238-2400 stope	Na (v) 500W 120V	2 at 3 m ht.	110	7.5	22

Underground Working Place	Mine and Location	Type of Light Source	Description	Highest Value (lx)	Lowest Value (lx)	Mean Value (lx)
Shop Workbench	#3 2350 L.	Hg (v) DX 1000W	3 rows of 5 lamps each 7m ht.	-	-	290
	#4 in garage	150W t. fil. PAR	single row of 5 lamps 1m from bench top	-	-	1500
	#6 2900 L. garage	direct: fluor indirect: Hg (v)	7 sets of 4 ft double tubed 2 rows at 4 m apart 5 lamps per row at 6m spacing 10m ht.	310	250	290
	#11 3250 L	300W t. fil. Refl. Flood heat resist.	wall mounted spotlights	240	130	200
Hoist Room	#11 5530 H.R. 3000 L	200W t. fil. Rough Service	-	75	27	43
Track Haulage way	#14 2400 L main x-cut	fluor. cool white	Single row 8 ft. double tubed at 3m spacing 3m ht.	220	130	170
Fuelling Station	#6 2900 L	Hg (v)	wall mounted	430	72	360

Underground Working Place	Mine and Location	Type of Light Source	Description	Highest Value (lx)	Lowest Value (lx)	Mean Value (lx)
Refuge Station	#3 2350 L. #2 shaft (table top)	fluor. cool white	two rows 8 ft. double tubed at 1m spacing 2.5m ht.	390	120	300
	#6 2900 L. large L.R. (table top)	40W fluor. daylight	single row 4 ft. double tubed at 0.5m spacing	200	34	95
	#6 2900 L. small L.R. (table top)	40W fluor. daylight	single row 4 ft. double tubed	240	150	190
	#11 3250 L.	100W t. fil.	1 bank of 5 bulbs at 2.5m centers	73	46	56
	#14 2400 L.	fluor. cool white	single row 8 ft. double tubed at 1m. spacing 3m ht.	650	220	430
Scoop Tram ramp	#4 C zone 208 stope	Na (v) 250V	13m between lamps at 8m ht.	160	5	50
	#6 2900 L.	Hg (v) 150W	8m between lamps at 3m ht.	46	15	32
Conveyor Ramp	#6 3025 L.	100W T.F. Rough Service	on spencer cable 5.5m intervals	110	4.3	54

Underground Working Place	Mine and Location	Type of Light Source	Description	Highest Value (lx)	Lowest Value (lx)	Mean Value (lx)
Crusher	#3 2950 L.	8 Hg (v) 4 t. fil.	-	54	5.4	30
	#5 2800 L.	Hg (v)	-	54	5.4	43
	#6 3025 L. (1m)	6-400W Hg (v) 2 t. fil. 4-125W Hg (v)	roof mounted platform mounted	220	56	190
	#11 3250 L.	300W t. fil. Extended Service	4 roof mounted at 11m ht.	37	13	20
Shifter's Office	#6 2900 L. lunchroom	40W fluor. daylight	single row at 4 ft. double row at 0.5m spacing	-	-	70
	#11 3250	40W fluor. cool white Extended Service	3 banks of 4 - 4 ft tubes	1300	650	1100
	#14 2400 L.	fluor. cool white	8 ft double tubed wall mounted at 3m ht	840	470	650

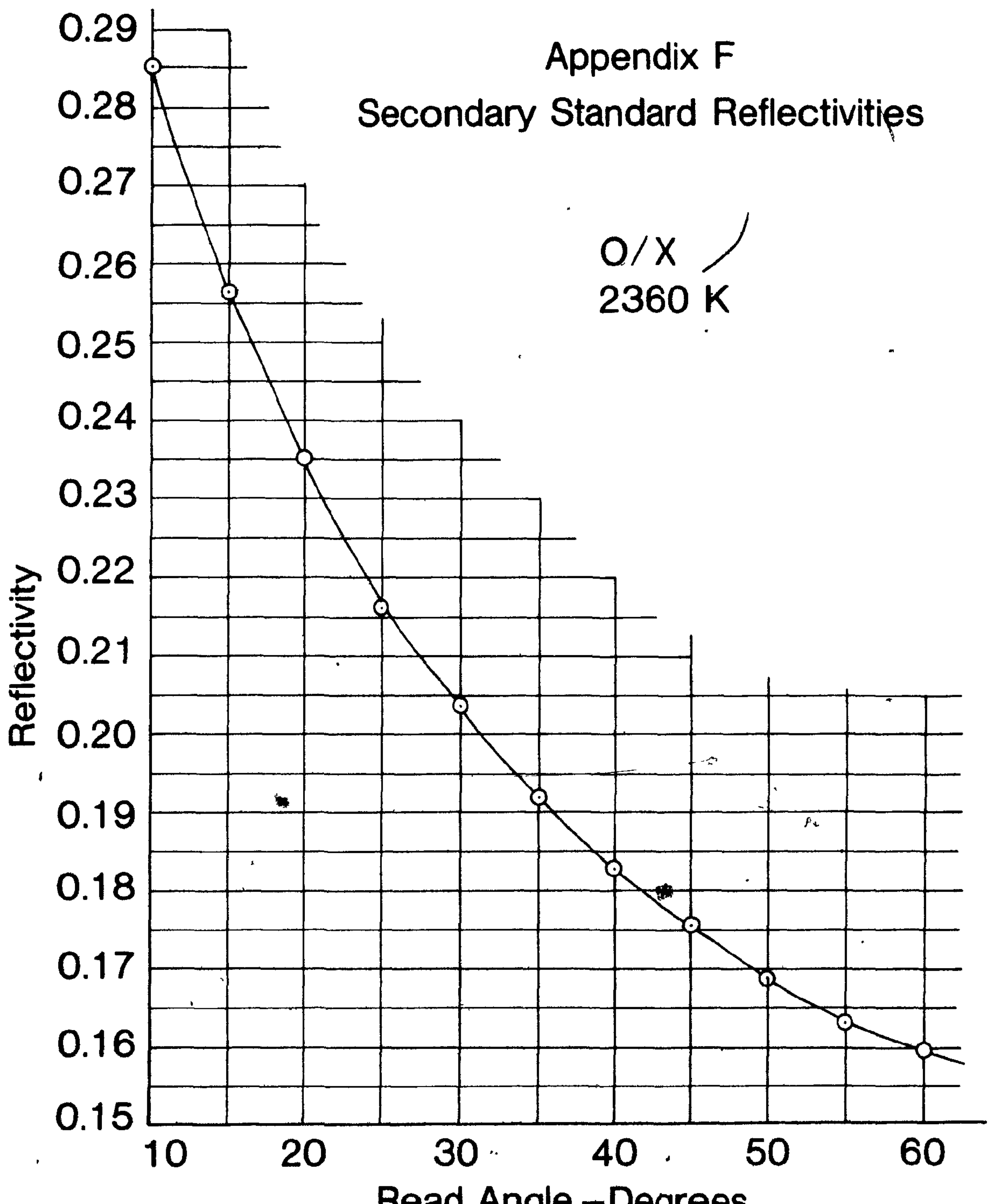
Underground Working Place	Mine and Location	Type of Light Source	Description	Highest Value (lx)	Lowest Value (lx)	Mean Value (lx)
Garage	#3 2350 L (floor)	Hg (v) DX 1000W	3 rows of 5 lamps each 7m ht.	1100	580	730
	#4 garage entrance	qtz. halogen	1 wall mounted 8.5m ht.	46	37	42
	#6 2900 L 0.8m ht.	Hg (v)	2 rows at 4m apart 5 lamps per row at 6m spacing 10m ht.	300	110	250
	#11 3250 L	150W t. fil. Rough Service	2 banks 6 bulbs per bank	260	54	120
	#14 2400 L	fluor. cool white	8 ft double tubed 8 wall mounted at 3m ht. 6 back mounted at 6m ht.	670	160	410
Charging Station	#5 2900 L	200W t. fil. G.E. 1000 h	1 bare bulb	-	-	53
	#6 2900 L	100W t. fil.	single bulb	-	-	52



Incident Angle – Degrees

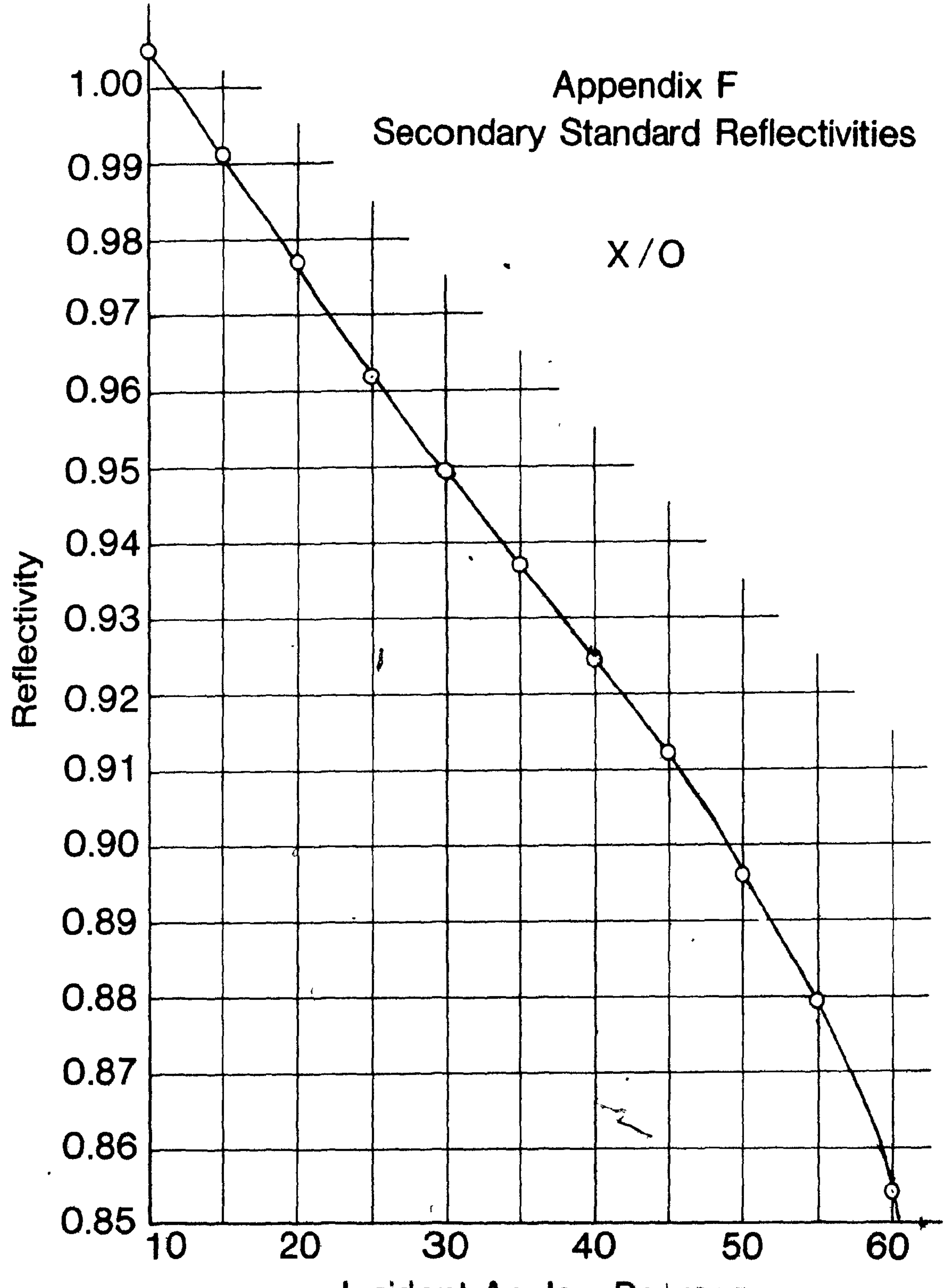
Kodak Grey Card Incident Angle Reflectivity

Figure 49



Kodak Grey Card Angle Reflectivity

Figure 50



Millipore Paper Incident Angle Reflectivity

Figure 51

SHEET NO. 5 of 10

APPENDIX G

TABLE 20

UNDERGROUND REFLECTIVITY REPORTING FORM

****

DATE Nov.14,1975
MINE Baker Talc
LOCATION 400 level at ore pass
OPERATOR LL
RECORDER DT
CALCULATED BY LL
CHECKED BY DT

LAMP NO. 100 watt T.F.
BATTERY NO. Verd-A-Ray

INCID.ANGLE 0°
RECORD ANGLE 45°
TEST-PLATE ANGLE Horizontal
REF. STD. PLATE 0.786
REF. TEST PLATE 0.175
"A" DIAL (3 F.C.) 233
AMBIENT TEMP. +10°C

WORKING LAMP STANDARDIZATION

	RDG NO.	"A" DIAL (ma)	"B" DIAL (ma)
CALIBRATION	1	233	268
	2	233	268
	3	233	268
	4	233	268
	5		
	6		
	7		
	MODE	233	268
RECALIB.	1	233	268
	2	233	268
	3		
	4		
	MODE	233	268

TEST-PLATE LUMINANCE

RDG NO.	"B" DIAL (ma)	SCALE RDG	(SCALE RDG)^2
1	268	2.53	6.4009
2	268	2.24	5.0176
3	268	2.30	5.2900
4	268	2.32	5.3824
5	268	2.44	5.9536
6	268	2.50	6.2500
7	268	2.57	6.6049
8			

FILTER NO. 31
POSITION 2

TOTAL= 40.8994
R.M.S.= 2.417
F.FACTOR= 0.108 X
STD. REF.= 0.786 X
AVG. LUMIN.(ft.L)= 0.205

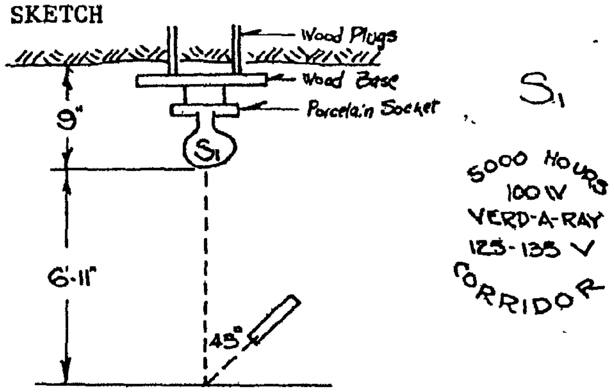
REFLECTIVITY OF TEST-OBJECT

FILTER NO. 31 FILTER POSITION 2 FILTER FACTOR 0.108

RDG NO.	NOTES	"B" DIAL (ma)	SCALE RDG X	STD REF. X F.FACTOR	LUMINANCE (ft.L) X	REF.T.PL. ÷ AV.L.T.PL =	REFLEC-TIVITY	$(x_j-\bar{x})^2$
1		268	2.37		0.202		0.172	0.000016
2		268	2.50	0.108X0.79=	0.213	0.175÷0.205=	0.181	0.000025
3		268	2.36	0.08532	0.201	0.85366	0.171	0.000025
4		268	2.47		0.211		0.179	0.000009
5		268	2.45		0.209		0.178	0.000004
6								
7								

	REFLECTIVITY	$(x_j-\bar{x})^2$
TOTAL	0.881	0.000079
MEAN	0.176	
STANDARD DEV.		0.004

SKETCH



DESCRIPTION OF TEST-OBJECT

Brown mud on floor, moist but not water saturated, well packed little to no contrast

APPENDIX H

REFLECTIVITY DATA

Description: Ore
Breccia, chalcopyrite in garnetized limestone

Ore Minerals 25% of field - top reading
Limestone 75% of field - bottom reading
Needle Mountain, 208 stope, 1718 Hwy

Incident Angle: 0° Tilt Angle: -

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.380, σ = 0.092; $\bar{R}$ = 0.242, σ = 0.037	Off Angle				
Read Angle	10°	15°	20°	25°	30°
0°	0.415 0.239	0.370 0.199	0.477 0.256	0.445 0.294	0.330 0.239
45°	0.477 0.245	0.477 0.239	0.239 0.239	0.239 0.256	0.287 0.234
90°	0.415 0.250	0.406 0.281	0.379 0.250	0.322 0.268	0.379 0.268
135°	0.250 0.194	0.315 0.213	0.388 0.239	0.256 0.250	- -
180°	0.362 0.190	0.338 0.234	- -	- -	- -
225°	0.477 0.287	0.268 0.281	0.466 0.288	0.315 0.281	0.379 0.199
270°	0.455 0.315	0.379 0.199	0.379 0.250	0.301 0.301	0.379 0.239
315°	0.560 0.239	0.338 0.213	0.370 0.228	0.600 0.165	0.455 0.151
$\bar{R}_x$	0.426	0.361	0.385	0.354	0.368
$\bar{R}_x$	0.245	0.232	0.250	0.259	0.222

REFLECTIVITY DATA

Description: Ore

Breccia, chalcopyrite in carcareous siltstone

Ore minerals 25% of field - top reading

Siltstone 75% of field - bottom reading

Needle Mountain, 208 stope, 1718 Hwy

Incident Angle: 0° Tilt Angle: -

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.484
σ = 0.112
$\bar{R}$ = 0.233
σ = 0.046

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	0.427 0.166	0.417 0.302	0.417 0.302	0.399 0.309	0.408 0.195
45°	0.417 0.257	0.399 0.170	0.538 0.302	0.590 0.263	0.408 0.282
90°	0.502 0.252	0.632 0.214	0.646 0.295	0.646 0.282	0.646 0.257
135°	0.563 0.252	0.514 0.191	0.502 0.246	0.525 0.204	- -
180°	0.632 0.209	0.709 0.235	- -	- -	- -
225°	0.617 0.246	0.417 0.209	0.408 0.269	0.427 0.138	0.437 0.162
270°	0.632 0.195	0.302 0.257	0.317 0.252	0.468 0.195	0.408 0.224
315°	0.331 0.159	0.399 0.200	0.603 0.240	0.408 0.195	0.314 0.257
$\bar{R}_x$	0.515	0.474	0.490	0.495	0.437
$\bar{R}_x$	0.217	0.222	0.272	0.227	0.230

REFLECTIVITY DATA

Description: Ore

Complex massive sulphide

Pentlandite and pyrrhotite, minor pyrite, bornite, chalcopyrite, norite inclusions, fresh, dry surface

Creighton Mine, 6100 L

Incident Angle: 0° Tilt Angle: -

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.233, σ = 0.048		Off Angle 10°	15°	20°	25°	30°
Read Angle	0°	0.192	0.192	0.201	0.206	0.176
	45°	0.248	0.192	0.291	0.180	0.153
	90°	0.237	0.242	0.237	0.172	0.153
	135°	0.242	0.305	0.192	0.242	-
	180°	0.305	0.184	-	-	-
	225°	0.153	0.216	0.153	0.172	0.237
	270°	0.237	0.202	0.272	0.231	0.153
	315°	0.272	0.216	0.242	0.188	0.172
	$\bar{R}_x$	0.236	0.219	0.227	0.199	0.174

REFLECTIVITY DATA

Description: Ore

Complex massive sulphide, oxidized dry surface, pentlandite and pyrrhotite with minor chalcopyrite, bornite, pyrite, prominent cleavage, crumbly, iridescent

Creighton Mine, 6100 L

Incident Angle: 0° Tilt Angle: 0°

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.177

σ = 0.034

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	0.159	0.152	0.156	0.159	0.156
45°	0.191	0.163	0.129	0.152	0.156
90°	0.166	0.163	0.271	0.149	0.149
135°	0.187	0.175	0.136	0.136	-
180°	0.241	0.159	-	-	-
225°	0.191	0.277	0.205	0.149	0.139
270°	0.196	0.205	0.196	0.187	0.149
315°	0.215	0.187	0.201	0.196	0.163
$\bar{R}_x$	0.193	0.185	0.185	0.161	0.152

REFLECTIVITY DATA

Description: Ore

Banded ore with bands of complex sulphides 1 cm ± thick separated by grey quartz bands 0.1 cm ± thick. Recognizable sulphide ores include pentlandite, pyrrhotite, pyrite, chalcopyrite.

Strathcona Mine, 2125 L 22-30-32 stope

Incident Angle: 0° Tilt Angle: -

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R} = 0.178$

$\sigma = 0.032$

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	0.152	0.205	0.215	0.171	0.136
45°	0.179	0.191	0.152	0.126	0.121
90°	0.210	0.171	0.163	0.152	0.136
135°	0.187	0.191	0.175	0.179	-
180°	0.187	0.200	-	-	-
225°	0.220	0.241	0.236	0.121	0.241
270°	0.200	0.187	0.210	0.179	0.159
315°	0.183	0.156	0.152	0.171	0.145
$\bar{R}_x$	0.190	0.193	0.186	0.157	0.156

REFLECTIVITY DATA

Description: Ore

Chalcopyrite, massive. No other ore minerals evident.

Strathcona Mine, 2125 L 22-30-32 stope

Incident Angle: 0^{o} Tilt Angle: -

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.285, σ = 0.112	Off Angle				
Read Angle	10^{o}	15^{o}	20^{o}	25^{o}	30^{o}
0^{o}	0.271	0.291	0.384	0.384	0.430
45^{o}	0.291	0.366	0.375	0.483	0.231
90^{o}	0.298	0.451	0.542	0.430	0.529
135^{o}	0.242	0.298	0.342	0.242	-
180^{o}	0.188	0.179	-	-	-
225^{o}	0.226	0.179	0.175	0.184	0.206
270^{o}	0.253	0.192	0.184	0.188	0.143
315^{o}	0.179	0.298	0.271	0.179	0.143
$\bar{R}_x$	0.244	0.282	0.325	0.299	0.280

REFLECTIVITY DATA

Description: Ore

Complex massive sulphides. Pentlandite, pyrrotite, minor pyrite, quartz, chalcopyrite.

Strathcona Mine

Incident Angle: 0^{o} Tilt Angle: -

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.349

σ = 0.054

Read Angle	Off Angle 10^{o}	15^{o}	20^{o}	25^{o}	30^{o}
0^{o}	0.267	0.344	0.352	0.344	0.306
45^{o}	0.336	0.293	0.232	0.344	0.413
90^{o}	0.433	0.352	0.261	0.286	0.336
135^{o}	0.413	0.352	0.336	0.279	-
180^{o}	0.433	0.328	-	-	-
225^{o}	0.433	0.344	0.344	0.328	0.377
270^{o}	0.377	0.344	0.413	0.386	0.360
315^{o}	0.344	0.299	0.306	0.328	0.217
$\bar{R}_x$	0.380	0.332	0.321	0.328	0.335

REFLECTIVITY DATA

Description: Ore

Complex massive sulphides; pentlandite and pyrrhotite with minor pyrite, augen quartz, and chalcopyrite.

Strathcona Mine

Incident Angle: 0° Tilt Angle: -

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.274

σ = 0.052

	Off Angle				
Read Angle	10°	15°	20°	25°	30°
0°	0.290	0.247	0.253	0.357	0.326
45°	0.201	0.290	0.318	0.304	0.152
90°	0.259	0.236	0.201	0.192	0.230
135°	0.271	0.284	0.311	0.206	-
180°	0.304	0.192	-	-	-
225°	0.304	0.304	0.365	0.365	0.333
270°	0.304	0.318	0.241	0.304	0.241
315°	0.271	0.271	0.326	0.230	0.253
$\bar{R}_x$	0.275	0.268	0.288	0.280	0.256

REFLECTIVITY DATA

Description: Ore

Complex massive sulphide; pentlandite and pyrrhotite with minor pyrite, quartz augen, and chalcopyrite.

Strathcona Mine

Incident Angle: 15° Tilt Angle: -

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.297

σ = 0.050

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	0.322	0.177	0.213	0.301	0.177
45°	0.250	0.315	0.307	0.301	0.239
90°	0.322	0.280	0.337	0.387	0.345
135°	0.337	0.322	0.244	0.353	-
180°	0.322	0.262	-	-	-
225°	0.301	0.307	0.294	0.322	0.262
270°	0.315	0.307	0.337	0.322	0.208
315°	0.301	0.387	0.294	0.307	0.315
$\bar{R}_x$	0.309	0.295	0.289	0.328	0.258

REFLECTIVITY DATA

Description: Ore

Complex massive sulphides; pentlandite and pyrrhotite with minor pyrite, augen quartz, and chalcopyrite.

Strathcona Mine

Incident Angle: 30° Tilt Angle: -

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.260

σ = 0.075

		Off Angle				
		10°	15°	20°	25°	30°
Read Angle	0°	0.306	0.343	0.226	0.285	0.211
	45°	0.343	0.292	0.327	0.279	0.351
	90°	0.221	0.335	0.376	0.403	0.343
	135°	0.351	0.306	0.343	0.221	-
	180°	0.335	0.221	-	-	-
	225°	0.226	0.285	0.157	0.226	0.153
	270°	0.272	0.176	0.176	0.211	0.172
	315°	0.207	0.176	0.140	0.176	0.184
	$\bar{R}_x$	0.283	0.267	0.249	0.257	0.236

REFLECTIVITY DATA

Description: Ore

Complex massive sulphide; pentlandite, pyrrhotite, minor pyrite, small quartz augens, chalcopyrite.

Strathcona Mine

Incident Angle: 45° Tilt Angle: –

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.184

σ = 0.048

		Off Angle				
		10°	15°	20°	25°	30°
Read Angle	0°	0.121	0.196	0.206	0.163	0.163
	45°	0.215	0.304	0.231	0.210	0.215
	90°	0.215	0.220	0.277	0.215	0.265
	135°	0.206	0.265	0.192	0.139	–
	180°	0.149	0.136	–	–	–
	225°	0.136	0.136	0.136	0.136	0.136
	270°	0.142	0.142	0.171	0.167	0.130
	315°	0.133	0.215	0.215	0.196	0.142
	$\bar{R}_x$	0.165	0.202	0.204	0.175	0.175

REFLECTIVITY DATA

Description: Ore

Complex massive sulphide in contact with norite. Contrast at contact measured. Top reading on specular surface of massive sulphide. Bottom reading on grey to black smooth norite face.

Strathcona Mine 2900 L

Incident Angle: 0^{o} Tilt Angle: 0^{o}

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.127
σ = 0.035
$\bar{R}$ = 0.096
σ = 0.028

Read Angle	Off Angle 10^{o}	15^{o}	20^{o}	25^{o}	30^{o}
0^{o}	0.091 0.145	0.115 0.120	0.115 0.135	0.078 0.129	0.159 0.074
45^{o}	0.182 0.052	0.145 0.093	0.085 0.091	0.151 0.048	0.065 0.076
90^{o}	0.080 0.091	0.159 0.145	0.170 0.048	0.096 0.060	0.089 0.105
135^{o}	0.118 0.058	0.138 0.048	0.138 0.060	0.107 0.590	- -
180^{o}	0.135 0.151	0.145 0.063	- -	- -	- -
225^{o}	0.186 0.120	0.129 0.093	0.191 0.063	0.151 0.060	0.178 0.129
270^{o}	0.129 0.145	0.145 0.129	0.091 0.170	0.115 0.162	0.151 0.076
315^{o}	0.096 0.135	0.062 0.052	0.151 0.102	0.120 0.080	0.102 0.076
$\bar{R}_x$	0.127	0.130	0.134	0.117	0.124
$\bar{R}_x$	0.112	0.093	0.096	0.085	0.089

REFLECTIVITY DATA

Description: Ore

Complex massive sulphide

Predominantly pyrite, with chalco and pentlandite

specular to semi specular. Highly specular off pyrite

crystal facets 1MM ±. Matches off facets not possible.

Strathcona Mine, 2900 L

Incident Angle: 0° Tilt Angle: -

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.120

σ = 0.029

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	0.138	0.109	0.090	0.109	0.110
45°	0.124	0.105	0.100	0.105	0.084
90°	0.110	0.242	0.097	0.152	0.121
135°	0.106	0.105	0.140	0.108	-
180°	0.124	0.105	-	-	-
225°	0.131	0.159	0.138	0.087	0.112
270°	0.095	0.145	0.143	0.120	0.091
315°	0.152	0.096	0.121	0.114	0.137
$\bar{R}_x$	0.123	0.133	0.118	0.114	0.109

REFLECTIVITY DATA

Description: Ore

Massive sulphide, pentlandite and pyrrhotite specular, oxidized surface, Cu : Ni = 1:15

Metallic, irridescent, gold bronze.

Birchtree Mine 108 orebody typical ore

Incident Angle: 0^{o} Tilt Angle: -

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.209

σ = 0.041

Read Angle	Off Angle 10^{o}	15^{o}	20^{o}	25^{o}	30^{o}
0^{o}	0.207	0.211	0.210	0.272	0.258
45^{o}	0.286	0.207	0.226	0.224	0.258
90^{o}	0.268	0.234	0.287	0.261	0.205
135^{o}	0.188	0.228	0.171	0.192	-
180^{o}	0.181	0.221	-	-	-
225^{o}	0.200	0.165	0.173	0.161	0.133
270^{o}	0.188	0.164	0.240	0.151	0.139
315^{o}	0.234	0.218	0.199	0.192	0.157
$\bar{R}_x$	0.219	0.206	0.215	0.208	0.192

REFLECTIVITY DATA

Description: Ore

Massive sulphides

Pentlandite and pyrrhotite, highly specular,

fresh surface, Cu : Ni = 1:15

Birchtree Mine 108 orebody typical ore

Incident Angle: 0^{o} Tilt Angle: -

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.242

σ = 0.060

Read Angle	Off Angle 10^{o}	15^{o}	20^{o}	25^{o}	30^{o}
0^{o}	0.232	0.336	0.273	0.413	0.292
45^{o}	0.292	0.217	0.292	0.249	0.299
90^{o}	0.193	0.243	0.217	0.150	0.243
135^{o}	0.185	0.157	0.232	0.161	-
180^{o}	0.232	0.180	-	-	-
225^{o}	0.261	0.249	0.238	0.185	0.189
270^{o}	0.232	0.147	0.232	0.193	0.222
315^{o}	0.279	0.306	0.328	0.344	0.232
$\bar{R}_x$	0.238	0.229	0.259	0.242	0.246

REFLECTIVITY DATA

Description: Ore

Massive chalco and other copper minerals

Flin Flon Mine, H.B.M.& S. South Main

4 V.P. square-set lower 3500 L hanging wall

Incident Angle: 0^{o} Tilt Angle: -

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.589

σ = 0.101

Read Angle	Off Angle 10^{o}	15^{o}	20^{o}	25^{o}	30^{o}
0^{o}	0.508	0.717	0.496	0.669	0.639
45^{o}	0.639	0.596	0.624	0.474	0.717
90^{o}	0.531	0.596	0.570	0.624	0.474
135^{o}	0.624	0.496	0.531	0.624	-
180^{o}	0.786	0.669	-	-	-
225^{o}	0.596	0.751	0.669	0.624	0.496
270^{o}	0.717	0.596	0.463	0.463	0.376
315^{o}	0.669	0.751	0.474	0.474	0.485
$\bar{R}_x$	0.634	0.647	0.547	0.565	0.531

REFLECTIVITY DATA

Description: Ore

Pyrite, sphalerite, minor chalcopyrite,

5% Zn, 2% Cu

Light diffuse surface 70% of field - top reading

Dark specular surface 30% of field - bottom reading

South Main Mine #4 V.P. square set

Incident Angle: 0° Tilt Angle: -

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R} = 0.168$
$\sigma = 0.027$

$\bar{R} = 0.064$
$\sigma = 0.010$

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	0.139 0.062	0.139 0.078	0.167 0.070	0.167 0.058	0.136 0.058
45°	0.175 0.057	0.152 0.067	0.171 0.058	0.192 0.078	0.145 0.062
90°	0.210 0.055	0.183 0.039	0.156 0.068	0.145 0.047	0.139 0.066
135°	0.192 0.055	0.183 0.049	0.163 0.076	0.139 0.057	- -
180°	0.220 0.061	0.201 0.075	- -	- -	- -
225°	0.183 0.062	0.156 0.070	0.139 0.063	0.149 0.053	0.220 0.073
270°	0.215 0.082	0.187 0.084	0.171 0.061	0.139 0.055	0.175 0.055
315°	0.139 0.062	0.145 0.078	0.139 0.088	0.149 0.062	0.210 0.054
$\bar{R}_x$	0.184	0.168	0.158	0.154	0.171
$\bar{R}_x$	0.062	0.068	0.069	0.059	0.061

REFLECTIVITY DATA

Description: Ore

Complex massive sulphide, mainly chalcopyrite and sphalerite.
clean, dry surface. Two distinct fields,
top reading on chalcopyrite 55% of field
bottom reading on sphalerite 45% of field

South Main Mine 4 V.P. Upper square set

Incident Angle: 0^{o} Tilt Angle: -

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.307
σ = 0.076
$\bar{R}$ = 0.185
σ = 0.048

Read Angle	Off Angle 10^{o}	Off Angle 15^{o}	Off Angle 20^{o}	Off Angle 25^{o}	Off Angle 30^{o}
0^{o}	0.224 0.224	0.331 0.288	0.355 0.282	0.309 0.269	0.282 0.282
45^{o}	0.178 0.141	0.269 0.170	0.209 0.195	0.229 0.195	0.204 0.178
90^{o}	0.288 0.158	0.331 0.148	0.240 0.155	0.234 0.148	0.214 0.148
135^{o}	0.302 0.148	0.269 0.066	0.295 0.117	0.263 0.148	- -
180^{o}	0.355 0.148	0.263 0.186	- -	- -	- -
225^{o}	0.282 0.145	0.371 0.155	0.363 0.178	0.389 0.183	0.371 0.191
270^{o}	0.407 0.234	0.355 0.219	0.389 0.178	0.417 0.209	0.417 0.178
315^{o}	0.295 0.148	0.371 0.200	0.331 0.200	0.245 0.234	0.417 0.219
$\bar{R}_x$	0.291	0.320	0.312	0.298	0.318
$\bar{R}_x$	0.168	0.179	0.186	0.198	0.199

REFLECTIVITY DATA

Description: Ore

Sphalerite, dusty surface

footwall contact 12% Zn

Flin Flon Mine, H.B.M.& S. South Main

4 V.P. lower square set

Incident Angle: 0° Tilt Angle: 0°

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.107

σ = 0.012

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	0.111	0.106	0.090	0.116	0.108
45°	0.127	0.127	0.090	0.108	0.086
90°	0.127	0.108	0.113	0.101	0.111
135°	0.108	0.108	0.108	0.101	-
180°	0.111	0.090	-	-	-
225°	0.127	0.113	0.108	0.116	0.113
270°	0.092	0.111	0.099	0.084	0.101
315°	0.118	0.108	0.121	0.099	0.092
$\bar{R}_x$	0.115	0.109	0.104	0.104	0.102

REFLECTIVITY DATA

Description: Ore

Run-of-muck from 1 V.P. 6 square set
pyrite, minor chalcopyrite and sphalerite,
fresh surface, little dust, dry

South Main Mine 3250 Crusher

Incident Angle: 0° Tilt Angle: -

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.253
σ = 0.038

		Off Angle				
		10°	15°	20°	25°	30°
Read Angle	0°	0.206	0.253	0.216	0.342	0.216
	45°	0.236	0.201	0.242	0.226	0.211
	90°	0.259	0.312	0.334	0.231	0.216
	135°	0.248	0.284	0.342	0.265	-
	180°	0.242	0.304	-	-	-
	225°	0.271	0.259	0.253	0.253	0.253
	270°	0.271	0.231	0.253	0.271	0.271
	315°	0.216	0.253	0.192	0.259	0.201
	$\bar{R}_x$	0.244	0.262	0.262	0.264	0.228

REFLECTIVITY DATA

Description: Ore.

Massive sulphides in contact with wall rock

Specular ore surface - top reading

Diffuse wall rock surface - bottom reading

fresh, clean.

South Main Mine

Incident Angle: 0° Tilt Angle: -

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.178
σ = 0.049

$\bar{R}$ = 0.096
σ = 0.014

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	0.261 0.109	0.222 0.109	0.125 0.086	0.232 0.093	0.227 0.106
45°	0.212 0.101	0.154 0.070	0.172 0.101	0.154 0.061	0.154 0.090
90°	0.147 0.097	0.109 0.073	0.165 0.090	0.143 0.061	0.122 0.109
135°	0.134 0.114	0.143 0.082	0.154 0.097	0.134 0.086	- -
180°	0.114 0.101	0.114 0.119	- -	- -	- -
225°	0.165 0.116	0.168 0.097	0.172 0.095	0.176 0.109	0.168 0.122
270°	0.180 0.093	0.176 0.097	0.143 0.082	0.217 0.109	0.185 0.097
315°	0.207 0.104	0.217 0.106	0.306 0.097	0.243 0.097	0.278 0.086
$\bar{R}_x$	0.177	0.163	0.177	0.186	0.189
$\bar{R}_x$	0.104	0.094	0.093	0.088	0.102

REFLECTIVITY DATA

Description: Ore

Complex massive sulphide, fresh dry surface

Stobie Mine

Incident Angle: 0^o Tilt Angle: 0^o

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.499

σ = 0.164

		Off Angle				
		10^o	15^o	20^o	25^o	30^o
Read Angle	0^o	0.507	0.385	0.232	0.385	0.260
	45^o	0.462	0.412	0.367	0.292	0.285
	90^o	0.543	0.519	0.367	0.442	0.462
	135^o	0.582	0.700	0.519	0.351	-
	180^o	0.700	0.750	-	-	-
	225^o	0.750	0.716	0.700	0.733	0.462
	270^o	0.442	0.716	0.733	0.653	0.596
	315^o	0.507	0.543	0.462	0.531	0.343
	$\bar{R}_x$	0.562	0.593	0.483	0.484	0.324

REFLECTIVITY DATA

Description: Ore

Massive Sulphides

High chalcopyrite + minor sphalerite, fresh, clean surface, brassy yellow, specular

Schist Lake Mine

Incident Angle: 0° Tilt Angle: -

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.189

σ = 0.043

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	0.187	0.163	0.159	0.159	0.210
45°	0.205	0.253	0.156	0.133	0.183
90°	0.163	0.159	0.167	0.201	0.163
135°	0.183	0.171	0.167	0.129	-
180°	0.187	0.210	-	-	-
225°	0.133	0.271	0.253	0.264	0.205
270°	0.247	0.163	0.271	0.145	0.241
315°	0.163	0.183	0.183	0.205	0.179
$\bar{R}_x$	0.184	0.197	0.194	0.177	0.197

REFLECTIVITY DATA

Description: Ore

Massive sulphide

Thompson Mine

Incident Angle: 15° Tilt Angle: 0°

Colour Temperature: 2360 K tungsten filament

$\bar{R}$ = 0.127

σ = 0.018

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	0.108	0.110	0.103	0.113	0.110
45°	0.127	0.116	0.110	0.121	0.116
90°	0.146	0.149	0.110	0.146	0.146
135°	0.116	0.163	0.139	0.149	-
180°	0.130	0.130	-	-	-
225°	0.130	0.130	0.146	0.113	0.108
270°	0.146	0.130	0.116	0.121	0.142
315°	0.179	0.139	0.116	0.121	0.094
$\bar{R}_x$	0.135	0.133	0.120	0.126	0.119

REFLECTIVITY DATA

Description: Ore

Massive sulphide

Thompson Mine

Incident Angle: 30° Tilt Angle: 0°

Colour Temperature: 2360 K tungsten filament | S.E.I.

$\bar{R}$ = 0.125

σ = 0.014

	Off Angle				
Read Angle	10°	15°	20°	25°	30°
0°	0.129	0.115	0.107	0.110	0.155
45°	0.135	0.129	0.118	0.115	0.120
90°	0.135	0.126	0.138	0.132	0.126
135°	0.107	0.129	0.107	0.102	-
180°	0.118	0.115	-	-	-
225°	0.155	0.129	0.129	0.120	0.102
270°	0.129	0.129	0.155	0.120	0.107
315°	0.135	0.135	0.135	0.123	0.123
$\bar{R}_x$	0.130	0.126	0.127	0.117	0.122

REFLECTIVITY DATA

Description: Ore

Massive Sulphide

Thompson Mine

Incident Angle: 45° (right) Tilt Angle: 0°

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.129

σ = 0.021

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	0.128	0.125	0.125	0.128	0.138
45°	0.154	0.107	0.123	0.100	0.104
[illegible]°	0.131	0.128	0.131	0.102	0.102
135°	0.104	0.107	0.104	0.109	-
180°	0.151	0.131	-	-	-
225°	0.158	0.151	0.128	0.151	0.151
270°	0.154	0.158	0.141	0.128	0.125
315°	0.169	0.131	0.151	0.089	0.144
$\bar{R}_x$	0.144	0.130	0.129	0.115	0.127

REFLECTIVITY DATA

Description: Ore

Disseminated to blebby complex sulphide with pyrrhotite, pentlandite predominating in highly chloritized host rock, chloritic rock striated, dull grey to shiny black.

Dull Grey 20% of field - top reading

Shiny Black 80% of field - bottom reading

Manibridge Mine

Incident Angle: 0^{o} Tilt Angle: -

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.186
σ = 0.032
$\bar{R}$ = 0.066
σ = 0.022

Read Angle	Off Angle 10^{o}	15^{o}	20^{o}	25^{o}	30^{o}
0^{o}	0.183 0.101	0,167 0.073	0.175 0.078	0.220 0.070	0.167 0.076
45^{o}	0.205 0.050	0.210 0.053	0.159 0.057	0.175 0.058	0.183 0.035
90^{o}	0.175 0.084	0.187 0.043	0.159 0.068	0.187 0.054	0.152 0.052
135^{o}	0.236 0.105	0.210 0.042	0.220 0.057	0.167 0.066	- -
180^{o}	0.159 0.052	0.110 0.050	- -	- -	- -
225^{o}	0.210 0.071	0.159 0.059	0.259 0.086	0.201 0.035	0.149 0.092
270^{o}	0.220 0.063	0.210 0.110	0.145 0.042	0.201 0.075	0.246 0.419
315^{o}	0.163 0.043	0.175 0.040	0.179 0.118	0.139 0.082	0.220 0.057
$\bar{R}_x$	0.194	0.179	0.185	0.184	0.186
$\bar{R}_x$	0.071	0.059	0.072	0.063	0.062

REFLECTIVITY DATA

Description: Ore

Blebby to disseminated complex sulphide ore in ultramafic

sulphides = 25%, ultramafic = 75%

Manibridge Mine, F.N.M.L. 4A stope

Incident Angle: 0° Tilt Angle: -

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.092

σ = 0.010

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	0.083	0.105	0.083	0.107	0.098
45°	0.107	0.091	0.102	0.096	0.102
90°	0.102	0.098	0.083	0.085	0.083
135°	0.100	0.091	0.085	0.110	-
180°	0.100	0.076	-	-	-
225°	0.102	0.107	0.098	0.087	0.091
270°	0.098	0.091	0.069	0.080	0.080
315°	0.100	0.083	0.081	0.085	0.080
$\bar{R}_x$	0.099	0.093	0.086	0.093	0.089

REFLECTIVITY DATA

Description: Ore

Run of muck

dirty, grey, dry, dusty, diffuse.

Ore minerals not identifiable

Brunswick Mine, 2950 Crusher Station

Incident Angle: 0^{o} Tilt Angle: 0^{o}

Colour Temperature: 2360 K tungsten filament M.I.

$\bar{R}$ = 0.152

σ = 0.011

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	-	0.155	-	0.145	-
45°	0.166	-	-	-	0.140
90°	-	0.157	-	-	0.136
135°	-	-	0.152	0.149	-
180°	0.169	0.157	-	-	-
225°	-	-	0.147	0.148	0.140
270°	0.167	-	-	-	-
315°	-	-	0.154	-	0.143
$\bar{R}_x$	0.167	0.156	0.151	0.147	0.140

REFLECTIVITY DATA

Description: Ore

Complex sulphide, pyrite dominating, also sphalerite, galena, pyrrhotite. Dissemination is very fine.

Dusty, dry surface.

Brunswick Mine, 62 F.W. 1900 West Ore Zone

Incident Angle: 0° Tilt Angle: 0°

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R} = 0.148$

$\sigma = 0.021$

		Off Angle				
		10°	15°	20°	25°	30°
Read Angle	0°	0.132	0.195	0.126	0.129	0.107
	45°	0.138	0.162	0.135	0.129	0.129
	90°	0.158	0.155	0.158	0.166	0.148
	135°	0.162	0.169	0.155	0.162	-
	180°	0.173	0.148	-	-	-
	225°	0.148	0.135	0.155	0.129	0.132
	270°	0.190	0.169	0.135	0.151	0.135
	315°	0.173	0.162	0.135	0.102	0.132
	$\bar{R}_x$	0.159	0.162	0.143	0.138	0.130

REFLECTIVITY DATA

Description: Ore

Talc,

White to grey, fine grained to powdery surface, diffuse dry.

White 33% of field - top reading

Grey 67% of field - bottom reading

Baker Talc Mine, 400 L , South Cross-cut

Incident Angle: 0^{o} Tilt Angle: 0^{o}

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.678
σ = 0.079
$\bar{R}$ = 0.337
σ = 0.040

Read Angle	Off Angle 10^{o}	15^{o}	20^{o}	25^{o}	30^{o}
0^{o}	0.576 0.306	0.636 0.339	0.717 0.359	0.662 0.409	0.717 0.337
45^{o}	0.801 0.385	0.689 0.409	0.589 0.342	0.671 0.331	0.673 0.351
90^{o}	0.702 0.380	0.815 0.335	0.768 0.409	0.625 0.372	0.809 0.306
135^{o}	0.623 0.336	0.661 0.345	0.642 0.348	0.573 0.336	- -
180^{o}	0.603 0.394	0.708 0.302	- -	- -	- -
225^{o}	0.651 0.337	0.646 0.300	0.751 0.352	0.682 0.245	0.586 0.274
270^{o}	0.670 0.336	0.701 0.305	0.670 0.348	0.785 0.275	0.685 0.289
315^{o}	0.773 0.363	0.668 0.289	0.689 0.339	0.759 0.355	0.443 0.280
$\bar{R}_x$	0.675	0.690	0.689	0.680	0.652
$\bar{R}_x$	0.355	0.328	0.357	0.332	0.306

REFLECTIVITY DATA

Description: Ore

Magnesite

White, crystalline, specular, homogeneous, clean, dry.

Kilmar Mine

Incident Angle: 0° Tilt Angle: -

Colour Temperature: 2360 K tungsten filament M.I.

$\bar{R} = 0.879$

$\sigma = 0.018$

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	-	0.874	-	0.892	-
45°	0.863	-	-	-	0.866
90°	-	0.903	-	-	0.877
135°	-	-	0.892	0.870	-
180°	0.896	0.899	-	-	-
225°	-	-	0.877	0.885	-
270°	0.889	-	-	-	0.859
315°	-	-	0.845	-	0.881
$\bar{R}_x$	0.883	0.892	0.871	0.882	0.871

REFLECTIVITY DATA

Description: Rock

Quartz diorite gneiss. Banded texture with altering white light grey and dark grey 1 cm ± bands. Thick bands allow separate readings.

Quartz band 30% of field - top reading
Diorite Band 30% of field - bottom reading
Q.D. Band 40% of field - intermediate reading

Strathcona Mine, 22-30-32 stope, F.W. rock

Incident Angle: 0° Tilt Angle: 0°

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.409
σ = 0.048
$\bar{R}$ = 0.285
σ = 0.042
$\bar{R}$ = 0.168
σ = 0.034

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	0.439 0.283 0.175	0.357 0.270 0.179	0.357 0.179 0.118	0.391 0.325 0.175	0.504 0.341 0.179
45°	0.459 0.277 0.179	0.373 0.283 0.183	0.382 0.252 0.127	0.365 0.264 0.156	0.419 0.277 0.142
90°	0.400 0.301 0.159	0.527 0.311 0.236	0.389 0.277 0.187	0.365 0.357 0.181	0.373 0.252 0.225
135°	0.365 0.325 0.215	0.400 0.278 0.191	0.348 0.252 0.171	0.400 0.252 0.191	- - -
180°	0.449 0.283 0.156	0.348 0.277 0.201	- - -	- - -	- - -
225°	0.419 0.391 0.183	0.459 0.283 0.225	0.470 0.382 0.179	0.449 0.333 0.201	0.373 0.264 0.142
270°	0.373 0.264 0.179	0.391 0.215 0.093	0.391 0.270 0.142	0.449 0.283 0.183	0.449 0.277 0.220
315°	0.449 0.303 0.142	0.357 0.225 0.191	0.357 0.264 0.167	0.504 0.283 0.187	0.429 0.290 0.241
$\bar{R}_x$	0.419	0.402	0.385	0.416	0.424
$\bar{R}_x$	0.303	0.268	0.268	0.300	0.284
$\bar{R}_x$	0.174	0.187	0.156	0.132	0.192

REFLECTIVITY DATA

Description: Rock

Quartz diorite, white to grey

Strathcona Mine 2125 L 22-30-32 stope

Incident Angle: 0° Tilt Angle: -

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.159

σ = 0.018

		Off Angle				
		10°	15°	20°	25°	30°
Read Angle	0°	0.183	0.163	0.167	0.163	0.183
	45°	0.163	0.156	0.152	0.163	0.139
	90°	0.175	0.156	0.163	0.156	0.163
	135°	0.139	0.130	0.130	0.175	-
	180°	0.167	0.171	-	-	-
	225°	0.098	0.156	0.187	0.149	0.156
	270°	0.183	0.175	0.179	0.130	0.139
	315°	0.149	0.205	0.149	0.163	0.163
	$\bar{R}_x$	0.157	0.164	0.161	0.157	0.157

REFLECTIVITY DATA

Description: Rock

Chlorite schist, some specularity, grey to green-grey, typical hanging wall cleavage plane.

Top readings taken with S.E.I.

Bottom readings taken with MacBeth.

Thompson Mine T-1 shaft 2400 L 2-38 stope

Incident Angle: 0° Tilt Angle: 0°

Colour Temperature: 2360 K tungsten filament S.E.I. & M.I.

$\bar{R} = 0.172$
$\sigma = 0.040$

$\bar{R} = 0.167$
$\sigma = 0.024$

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	0.187 0.197	0.191 0.193	0.182 0.183	0.163 0.165	0.107 0.156
45°	0.187 0.221	0.230 0.219	0.241 0.199	0.209 0.177	0.170 0.168
90°	0.214 0.209	0.241 0.205	0.205 0.191	0.241 0.182	0.200 0.167
135°	0.219 0.196	0.191 0.182	0.200 0.176	0.163 0.169	- -
180°	0.152 0.175	0.152 0.162	- -	- -	- -
225°	0.126 0.162	0.138 0.154	0.121 0.148	0.115 0.136	0.1[illegible]1 0.132
270°	0.152 0.176	0.145 0.159	0.191 0.147	0.159 0.140	0.121 0.130
315°	0.191 0.190	0.163 0.178	0.152 0.159	0.121 0.150	0.115 0.144
$\bar{R}_x$	0.179	0.181	0.185	0.167	0.139
$\bar{R}_x$	0.191	0.182	0.172	0.136	0.150

REFLECTIVITY DATA

Description: Rock

Chlorite schist, slightly specular, grey to green-grey, typical hanging wall cleavage plane.

Thompson Mine   T-1 shaft   2400 L   2-38 stope

Incident Angle: 15° Tilt Angle: 0°

Colour Temperature: 2360 K tungsten filament   S.E.I.

$\bar{R}$ = 0.123

σ = 0.021

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	0.143	0.125	0.104	0.111	0.119
45°	0.099	0.119	0.119	0.125	0.128
90°	0.157	0.189	0.157	0.157	0.147
135°	0.099	0.114	0.109	0.104	-
180°	0.131	0.147	-	-	-
225°	0.119	0.099	0.140	0.114	0.099
270°	0.131	0.119	0.147	0.104	0.114
315°	0.122	0.125	0.104	0.104	0.099
$\bar{R}_x$	0.125	0.130	0.126	0.117	0.118

REFLECTIVITY DATA

Description: Rock

Chlorite schist, slightly specular, grey to green-grey, typical hanging wall cleavage plane

Thompson Mine T-1 shaft 2400 L 2-38 stope

Incident Angle: 30° Tilt Angle: 0°

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R} = 0.106$

$\sigma = 0.019$

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	0.108	0.108	0.108	0.111	0.133
45°	0.116	0.096	0.088	0.088	0.103
90°	0.096	0.121	0.111	0.088	0.124
135°	0.130	0.118	0.099	0.070	-
180°	0.106	0.082	-	-	-
225°	0.139	0.092	0.101	0.111	0.108
270°	0.090	0.101	0.160	0.111	0.142
315°	0.094	0.090	0.103	0.084	0.070
$\bar{R}_x$	0.110	0.101	0.110	0.095	0.113

REFLECTIVITY DATA

Description: Rock

Chlorite schist, slightly specular, grey to green-grey, typical hanging wall cleavage plane.

Thompson Mine T-1 shaft 2400 L 2-38 stope

Incident Angle: 45° Tilt Angle: 0°

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.116

σ = 0.031

	Off Angle				
Read Angle	10°	15°	20°	25°	30°
0°	0.113	0.085	0.110	0.105	0.092
45°	0.076	0.135	0.105	0.132	0.092
90°	0.092	0.108	0.068	0.085	0.083
135°	0.089	0.108	0.103	0.085	-
180°	0.085	0.195	-	-	-
225°	0.118	0.132	0.113	0.192	0.145
270°	0.110	0.108	0.170	0.174	0.159
315°	0.132	0.110	0.135	0.152	0.085
$\bar{R}_x$	0.102	0.123	0.115	0.132	0.109

REFLECTIVITY DATA

Description: Rock

Biotite schist, grey, highly specular with diffuse bands. Specular dark and diffuse light bands interchange with viewing angle.

Diffuse surface 50% of field gives some variation - top reading
Specular surface, 50% of field shows high variation - bottom reading

Thompson Mine T-1 shaft 2400 L 2-38 stope F.W.

Incident Angle: 0^o Tilt Angle: 0^o

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.288
σ = 0.056
$\bar{R}$ = 0.208
σ = 0.100

Read Angle	Off Angle 10^o	Off Angle 15^o	Off Angle 20^o	Off Angle 25^o	Off Angle 30^o
0^o	0.315 0.158	0.269 0.141	0.256 0.141	0.308 0.135	0.315 0.223
45^o	0.315 0.182	0.308 0.129	0.256 0.199	0.239 0.158	0.223 0.123
90^o	0.262 0.126	0.269 0.166	0.275 0.177	0.213 0.126	0.223 0.102
135^o	0.256 0.155	0.256 0.222	0.239 0.120	0.223 0.126	- -
180^o	0.362 0.199	0.294 0.158	- -	- -	- -
225^o	0.308 0.397	0.323 0.379	0.354 0.199	0.251 0.330	0.199 0.406
270^o	0.288 0.120	0.269 0.416	0.281 0.406	0.281 0.397	0.262 0.330
315^o	0.330 0.135	0.426 0.194	0.232 0.151	0.467 0.190	0.315 0.158
$\bar{R}_x$	0.305	0.302	0.283	0.283	0.256
$\bar{R}_x$	0.184	0.226	0.199	0.209	0.224

REFLECTIVITY DATA

Description: Rock

Biotite gneiss, light grey to dark grey, dry, clean, some specularity off plagioclase, fresh grainy surface

Birchtree Mine 108 orebody, typical hanging wall rock

Incident Angle: 0^{o} Tilt Angle: 0^{o}

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.181

σ = 0.019

Read Angle	Off Angle 10^{o}	15^{o}	20^{o}	25^{o}	30^{o}
0^{o}	0.204	0.216	0.194	0.190	0.188
45^{o}	0.210	0.194	0.167	0.169	0.188
90^{o}	0.196	0.149	0.190	0.179	0.167
135^{o}	0.176	0.185	0.153	0.173	-
180^{o}	0.153	0.172	-	-	-
225^{o}	0.210	0.205	0.177	0.211	0.151
270^{o}	0.172	0.160	0.166	0.168	0.190
315^{o}	0.194	0.176	0.162	0.194	0.156
$\bar{R}_x$	0.189	0.182	0.173	0.183	0.173

REFLECTIVITY DATA

Description: Rock

Serpentine schist, green, platy cleavage, dry, clean

Manibridge Mine

Incident Angle: 0^{o} Tilt Angle: -

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.298

σ = 0.040

Read Angle	Off Angle 10^{o}	15^{o}	20^{o}	25^{o}	30^{o}
0^{o}	0.342	0.284	0.305	0.226	0.284
45^{o}	0.358	0.298	0.231	0.226	0.254
90^{o}	0.298	0.334	0.284	0.272	0.254
135^{o}	0.358	0.278	0.305	0.248	-
180^{o}	0.319	0.342	-	-	-
225^{o}	0.334	0.358	0.284	0.366	0.278
270^{o}	0.358	0.272	0.254	0.291	0.284
315^{o}	0.284	0.342	0.319	0.298	0.291
$\bar{R}_x$	0.331	0.314	0.283	0.275	0.274

REFLECTIVITY DATA

Description: Rock

Serpentine schist, white to greenish white, fibrous, high gloss areas change position with changes in off and record angles. Top reading on diffuse areas, bottom reading on gloss areas.

Manibridge Mine

Incident Angle: 0° Tilt Angle: -

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.394
σ = 0.074
$\bar{R}$ = 0.676
σ = 0.181

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	0.363 0.913	0.347 0.692	0.302 0.795	0.324 0.576	0.380 0.742
45°	0.347 0.956	0.408 0.677	0.289 0.513	0.355 0.576	0.398 0.661
90°	0.437 1.024	0.437 1.024	0.363 0.913	0.513 0.913	0.363 0.502
135°	0.589 0.832	0.468 0.457	0.408 0.725	0.537 0.913	- -
180°	0.479 0.913	0.513 0.725	- -	- -	- -
225°	0.355 0.457	0.355 0.576	0.380 0.576	0.502 0.502	0.408 0.408
270°	0.380 0.513	0.372 0.759	0.447 0.576	0.437 0.479	0.289 0.363
315°	0.363 0.708	0.302 0.646	0.339 0.576	0.289 0.589	0.363 0.576
$\bar{R}_x$	0.414	0.400	0.361	0.422	0.367
$\bar{R}_x$	0.790	0.694	0.668	0.650	0.542

REFLECTIVITY DATA

Description: Rock

Pegmatite, granite, clean, dry, predominantly pink feldspar, specular on striated surfaces.

Manibridge Mine

Incident Angle: 0° Tilt Angle: -

Colour Temperature: 2360 K tungsten filament M.I.

$\bar{R}$ = 0.247

σ = 0.014

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	0.265	0.223	0.254	0.246	0.237
45°	0.233	0.229	0.220	0.248	0.243
90°	0.237	0.250	0.261	0.248	0.242
135°	0.254	0.257	0.259	0.257	-
180°	0.243	0.256	-	-	-
225°	0.264	0.251	0.254	0.251	0.248
270°	0.255	0.265	0.222	0.265	0.251
315°	0.227	0.218	0.254	0.240	0.259
$\bar{R}_x$	0.247	0.244	0.246	0.251	0.247

REFLECTIVITY DATA

Description: Rock

Ultramafic, coarse grained, dark grey to black to green due to epidote.

Clean fresh surface, diffuse.

Manibridge Mine 5th L Hanging Wall Rock

Incident Angle: 0^{o} Tilt Angle: -

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.070

σ = 0.008

Read Angle	Off Angle 10^{o}	15^{o}	20^{o}	25^{o}	30^{o}
0^{o}	0.058	0.060	0.061	0.075	0.075
45^{o}	0.073	0.073	0.061	0.064	0.072
90^{o}	0.061	0.067	0.064	0.075	0.061
135^{o}	0.073	0.064	0.061	0.065	-
180^{o}	0.082	0.070	-	-	-
225^{o}	0.077	0.075	0.082	0.064	0.079
270^{o}	0.058	0.064	0.065	0.064	0.064
315^{o}	0.080	0.092	0.077	0.075	0.077
$\bar{R}_x$	0.070	0.071	0.067	0.069	0.071

REFLECTIVITY DATA

Description: Rock

Ultramafic; dark grey, clean, dry surface, dull diffuse, hackly fracture, preferential cleavage on white to light grey carbonate veinlets.

Manibridge Mine

Incident Angle: 0° Tilt Angle: -

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.096

σ = 0.012

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	0.096	0.086	0.092	0.113	0.096
45°	0.113	0.094	0.078	0.094	0.090
90°	0.096	0.096	0.086	0.094	0.090
135°	0.101	0.096	0.086	0.082	-
180°	0.082	0.084	-	-	-
225°	0.108	0.101	0.092	0.092	0.086
270°	0.082	0.094	0.118	0.098	0.090
315°	0.088	0.124	0.121	0.113	0.108
$\bar{R}_x$	0.096	0.097	0.096	0.098	0.093

REFLECTIVITY DATA

Description: Rock

Diorite, typical footwall rock, near contact, dry, clean

Flin Flon Mine, H.B.M. & S. South Main

4 V.P. upper

Incident Angle: 0° Tilt Angle: -

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.135

σ = 0.018

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	0.138	0.102	0.123	0.123	0.155
45°	0.151	0.129	0.145	0.123	0.148
90°	0.158	0.148	0.135	0.155	0.148
135°	0.145	0.155	0.138	0.151	-
180°	0.148	0.155	-	-	-
225°	0.151	0.155	0.115	0.158	0.129
270°	0.126	0.123	0.115	0.155	0.110
315°	0.117	0.120	0.117	0.102	0.110
$\bar{R}_x$	0.142	0.136	0.127	0.138	0.133

REFLECTIVITY DATA

Description: Rock

Diorite, footwall

South Main Mine, 4 V.P. square set

Incident Angle: 0^{o} Tilt Angle: -

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.131

σ = 0.016

		Off Angle				
		10^{o}	15^{o}	20^{o}	25^{o}	30^{o}
Read Angle	0^{o}	0.137	0.134	0.137	0.116	0.165
	45^{o}	0.131	0.137	0.143	0.114	0.137
	90^{o}	0.143	0.140	0.134	0.104	0.104
	135^{o}	0.109	0.122	0.122	0.109	-
	180^{o}	0.161	0.116	-	-	-
	225^{o}	0.137	0.137	0.128	0.131	0.125
	270^{o}	0.143	0.119	0.114	0.109	0.137
	315^{o}	0.172	0.134	0.143	0.137	0.137
	$\bar{R}_x$	0.142	0.130	0.132	0.117	0.134

REFLECTIVITY DATA

Description: Rock

Serpentine, fresh surface, some specularity

grey to off-white, smooth, conchoidal

South Main 3250 L Shop

Incident Angle: 0^{o} Tilt Angle: -

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.187

σ = 0.046

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	0.116	0.207	0.243	0.127	0.207
45°	0.164	0.125	0.249	0.202	0.260
90°	0.207	0.222	0.130	0.176	0.189
135°	0.157	0.097	0.202	0.197	-
180°	0.146	0.202	-	-	-
225°	0.193	0.216	0.143	0.207	0.133
270°	0.130	0.207	0.197	0.202	0.193
315°	0.176	0.216	0.207	0.153	0.328
$\bar{R}_x$	0.161	0.186	0.196	0.181	0.218

REFLECTIVITY DATA

Description: Rock

Gabbro

Flin Flon Mine, H.B.M.& S. South Main

3250 Crusher Station Typical country rock

Incident Angle: 0° Tilt Angle: -

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.093

σ = 0.011

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	0.079	0.096	0.098	0.107	0.102
45°	0.087	0.078	0.091	0.093	0.093
90°	0.091	0.076	0.096	0.076	0.076
135°	0.100	0.107	0.079	0.081	-
180°	0.076	0.098	-	-	-
225°	0.089	0.091	0.107	0.115	0.115
270°	0.081	0.096	0.093	0.107	0.096
315°	0.076	0.100	0.098	0.085	0.120
$\bar{R}_x$	0.085	0.093	0.095	0.095	0.100

REFLECTIVITY DATA

Description: Rock

Norite

Top reading on dry surface

Bottom reading on wet surface

Flaconbridge Mine, #5 shaft, 2800 L Charging station

Incident Angle: 0° Tilt Angle: -

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.191
σ = 0.020
$\bar{R}$ = 0.068
σ = 0.011

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	0.191 0.076	0.225 0.065	0.170 0.068	0.163 0.085	0.196 0.066
45°	0.183 0.062	0.178 0.063	0.200 0.054	0.187 0.054	0.191 0.059
90°	0.210 0.048	0.200 0.054	0.196 0.058	0.205 0.071	0.183 0.054
135°	0.148 0.085	0.235 0.068	0.187 0.068	0.174 0.069	- -
180°	0.196 0.056	0.187 0.046	- -	- -	- -
225°	0.205 0.085	0.200 0.083	0.230 0.069	0.191 0.065	0.191 0.059
270°	0.196 0.085	0.205 0.081	0.210 0.068	0.174 0.065	0.155 0.069
315°	0.170 0.085	0.155 0.085	0.196 0.065	0.196 0.081	0.191 0.074
$\bar{R}_x$	0.187	0.198	0.198	0.184	0.184
$\bar{R}_x$	0.073	0.068	0.064	0.070	0.064

REFLECTIVITY DATA

Description: Rock

Norite

Top reading on dry surface

Bottom reading on wet surface

Falconbridge Mine, #5 shaft, 2800 L Charging station

Incident Angle: 15^{o} Tilt Angle: -

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.193
σ = 0.024
$\bar{R}$ = 0.058
σ = 0.011

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	0.203 0.057	0.168 0.044	0.172 0.058	0.222 0.056	0.189 0.056
45°	0.207 0.072	0.207 0.068	0.193 0.084	0.157 0.068	0.198 0.053
90°	0.207 0.061	0.243 0.062	0.180 0.073	0.198 0.088	0.172 0.067
135°	0.198 0.070	0.172 0.058	0.207 0.057	0.207 0.060	- -
180°	0.203 0.070	0.198 0.044	- -	- -	- -
225°	0.165 0.062	0.255 0.054	0.203 0.051	0.193 0.044	0.161 0.044
270°	0.161 0.053	0.161 0.054	0.154 0.053	0.198 0.053	0.203 0.044
315°	0.203 0.050	0.203 0.053	0.203 0.050	0.217 0.042	0.161 0.056
$\bar{R}_x$	0.193	0.201	0.187	0.199	0.181
$\bar{R}_x$	0.062	0.055	0.061	0.059	0.053

REFLECTIVITY DATA

Description: Rock

Norite

Top reading on dry surface

Bottom reading on wet surface

Falconbridge Mine, #5 shaft, 2800 L Charging station

Incident Angle: 30° Tilt Angle: -

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.195
σ = 0.019
$\bar{R}$ = 0.050
σ = 0.008

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	0.179 0.039	0.216 0.041	0.201 0.039	0.179 0.042	0.192 0.039
45°	0.183 0.039	0.226 0.058	0.183 0.063	0.171 0.071	0.192 0.065
90°	0.226 0.043	0.179 0.049	0.221 0.055	0.221 0.052	0.188 0.065
135°	0.179 0.049	0.183 0.059	0.183 0.059	0.160 0.057	- -
180°	0.221 0.049	0.179 0.052	- -	- -	- -
225°	0.192 0.047	0.197 0.049	0.201 0.049	0.221 0.050	0.179 0.048
270°	0.183 0.039	0.197 0.049	0.226 0.052	0.192 0.049	0.226 0.041
315°	0.179 0.041	0.179 0.049	0.221 0.049	0.188 0.047	0.179 0.039
$\bar{R}_x$	0.193	0.194	0.205	0.190	0.193
$\bar{\bar{R}}_x$	0.043	0.051	0.052	0.053	0.050

REFLECTIVITY DATA

Description: Rock

Norite

Top reading on dry surface

Bottom reading on wet surface

Falconbridge Mine, #5 shaft, 2800 L Charging station

Incident Angle: 45° Tilt Angle: -

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.213
σ = 0.024
$\bar{R}$ = 0.049
σ = 0.006

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	0.200 0.042	0.183 0.048	0.196 0.045	0.210 0.048	0.191 0.044
45°	0.270 0.048	0.220 0.051	0.241 0.050	0.196 0.058	0.220 0.046
90°	0.171 0.044	0.183 0.048	0.210 0.047	0.174 0.048	0.174 0.048
135°	0.241 0.059	0.220 0.049	0.187 0.047	0.187 0.068	- -
180°	0.225 0.048	0.215 0.047	- -	- -	- -
225°	0.247 0.042	0.236 0.038	0.196 0.041	0.236 0.039	0.230 0.040
270°	0.225 0.053	0.225 0.054	0.241 0.044	0.230 0.054	0.241 0.053
315°	0.220 0.058	0.215 0.056	0.215 0.054	0.191 0.053	0.215 0.055
$\bar{R}_x$	0.225	0.212	0.212	0.203	0.212
$\bar{R}_x$	0.049	0.049	0.047	0.053	0.048

REFLECTIVITY DATA

Description: Rock

Quartz diorite

Light grey, diffuse

Falconbridge Mine, #5 shaft 2500 level Charging station

Incident Angle: 0° Tilt Angle: 0°

Colour Temperature: 2360 K tungsten filament M.I.

$\bar{R}$ = 0.300

σ = 0.017

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	-	0.260	-	0.292	-
45°	0.355	-	-	-	0.331
90°	-	0.314	-	-	0.319
135°	-	-	0.296	0.289	-
180°	0.278	0.326	-	-	-
225°	-	-	0.280	0.301	-
270°	0.325	-	-	-	0.275
315°	-	-	0.267	-	0.293
$\bar{R}_x$	0.319	0.300	0.281	0.294	0.304

REFLECTIVITY DATA

Description: Rock

Calcareous siltstone. Host rock for sulphide ore.

Needle Mountain Mine.

Incident Angle: 0° Tilt Angle: -

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R} = 0.512$, $\sigma = 0.050$		Off Angle				
		10°	15°	20°	25°	30°
Read Angle	0°	0.478	0.456	0.456	0.489	0.489
	45°	0.489	0.500	0.456	0.467	0.467
	90°	0.500	0.524	0.630	0.500	0.536
	135°	0.456	0.644	0.574	0.536	-
	180°	0.574	0.524	-	-	-
	225°	0.416	0.489	0.512	0.512	0.561
	270°	0.512	0.615	0.500	0.512	0.548
	315°	0.456	0.489	0.500	0.536	0.536
	$\bar{R}_x$	0.485	0.530	0.518	0.507	0.523

REFLECTIVITY DATA

Description: Rock

Unidentified back fill from fill stope

Top readings using S.E.I. on wet muddy surface

Bottom readings using MacBeth on very dusty, dry surface

Brunswick Mine 62 F.W. 1900 West Ore Zone

Incident Angle: 0° Tilt Angle: 0°

Colour Temperature: 2360 K tungsten filament S.E.I. & M.I.

$\bar{R}$ = 0.130
σ = 0.018
$\bar{R}$ = 0.276
σ = 0.011

		Off Angle				
		10°	15°	20°	25°	30°
Read Angle	0°	0.127 0.276	0.146 0.274	0.139 0.281	0.149 0.278	0.160 0.262
	45°	0.111 0.306	0.139 0.291	0.139 0.275	0.106 0.273	0.106 0.256
	90°	0.164 0.281	0.139 0.282	0.146 0.274	0.113 0.274	0.130 0.273
	135°	0.160 0.283	0.119 0.286	0.139 0.273	0.090 0.270	- -
	180°	0.143 0.301	0.130 0.277	- -	- -	- -
	225°	0.133 0.281	0.133 0.278	0.133 0.265	0.108 0.265	0.106 0.262
	270°	0.127 0.289	0.136 0.279	0.136 0.271	0.106 0.263	0.133 0.261
	315°	0.146 0.291	0.130 0.280	0.108 0.280	0.133 0.273	0.103 0.251
	$\bar{R}_x$	0.139	0.134	0.134	0.115	0.123
	$\bar{R}_x$	0.289	0.281	0.274	0.271	0.261

REFLECTIVITY DATA

Description: Rock

Backfill from fill stope, wet, muddy, uniform grey field.

Brunswick Mine 62 F.W., 1900 West Ore Zone

Incident Angle: 15° Tilt Angle: 0°

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.127

σ = 0.027

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	0.109	0.123	0.126	0.109	0.117
45°	0.129	0.138	0.162	0.129	0.109
90°	0.155	0.169	0.181	0.169	0.195
135°	0.109	0.141	0.138	0.148	-
180°	0.126	0.109	-	-	-
225°	0.104	0.120	0.087	0.089	0.087
270°	0.135	0.132	0.169	0.109	0.087
315°	0.138	0.117	0.107	0.104	0.104
$\bar{R}_x$	0.126	0.128	0.139	0.122	0.117

REFLECTIVITY DATA

Description: Rock

Backfill from fill stope, wet, muddy, uniform grey surface.

Brunswick Mine, 62 F.W. 1900 West Ore Zone

Incident Angle: 30° Tilt Angle: 0°

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.091

σ = 0.010

		Off Angle				
		10°	15°	20°	25°	30°
Read Angle	0°	0.090	0.097	0.097	0.090	0.093
	45°	0.097	0.093	0.086	0.097	0.099
	90°	0.081	0.079	0.097	0.097	0.097
	135°	0.095	0.097	0.097	0.077	-
	180°	0.104	0.074	-	-	-
	225°	0.101	0.101	0.077	0.077	0.081
	270°	0.097	0.082	0.081	0.077	0.097
	315°	0.117	0.081	0.095	0.097	0.077
	$\bar{R}_x$	0.098	0.088	0.090	0.087	0.091

REFLECTIVITY DATA

Description: Rock

Backfill from fill stope, wet, muddy,

uniform grey field.

Brunswick Mine 62 F.W. 1900 West Ore Zone

Incident Angle: 45^{o} Tilt Angle: 0^{o}

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.077

σ = 0.007

		Off Angle				
		10^{o}	15^{o}	20^{o}	25^{o}	30^{o}
Read Angle	0^{o}	0.075	0.078	0.084	0.080	0.075
	45^{o}	0.080	0.090	0.075	0.078	0.072
	90^{o}	0.077	0.075	0.078	0.073	0.072
	135^{o}	0.077	0.072	0.077	0.073	-
	180^{o}	0.078	0.068	-	-	-
	225^{o}	0.092	0.078	0.075	0.077	0.075
	270^{o}	0.080	0.060	0.072	0.075	0.070
	315^{o}	0.082	0.073	0.097	0.084	0.064
	$\bar{R}_x$	0.080	0.074	0.080	0.077	0.071

REFLECTIVITY DATA

Description: Rock

Slate, country wall rock

light to dark grey

Brunswick Mine, 62 F.W. 1900 West Ore Zone

Incident Angle: 0° Tilt Angle: 0°

Colour Temperature: 2360 K tungsten filament M.I.

$\bar{R}$ = 0.234

σ = 0.046

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	–	0.276	–	0.201	–
45°	0.271	–	–	–	0.206
90°	–	0.250	–	–	0.198
135°	–	–	0.236	0.213	–
180°	0.287	0.256	–	–	–
225°	–	–	0.249	0.213	–
270°	0.338	–	–	–	0.178
315°	–	–	0.210	–	0.157
$\bar{R}_x$	0.299	0.261	0.232	0.209	0.185

REFLECTIVITY DATA

Description: Rock

Sericite schist

Grey, some white (carbonate).

Minor yellow-orange (iron oxide), striated, slickensided

clean, dry.

Brunswick Mine 2350 L Lunch room wall

Incident Angle: 0° Tilt Angle: 0°

Colour Temperature: 2360 K tungsten filament M.I.

$\bar{R}$ = 0.279

σ = 0.011

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	-	-	-	-	0.270
45°	-	-	0.277	-	-
90°	-	0.277	-	-	0.269
135°	-	-	-	0.267	-
180°	0.291	-	-	-	-
225°	-	-	0.275	-	-
270°	-	-	-	.280	-
315°	0.299	0.289	-	-	-
$\bar{R}_x$	0.295	0.283	0.276	0.274	0.270

REFLECTIVITY DATA

Description: Paint

Whitewash on sericite schist

Flat white to grey to pale yellow, dry.

Diffuse, not fresh, 2+ a

Brunswick Mine 2350 L Lunch Room Wall

Incident Angle: 0° Tilt Angle: 0°

Colour Temperature: 2360 K tungsten filament M.I.

$\bar{R} = 0.457$

$\sigma = 0.024$

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	-	-	-	-	0.433
45°	-	-	0.442	-	-
90°	-	0.459	-	-	0.417
135°	-	-	-	0.428	-
180°	0.458	-	-	-	-
225°	-	-	0.456	-	-
270°	-	-	-	0.472	-
315°	0.506	0.494	-	-	-
$\bar{R}_x$	0.482	0.477	0.449	0.450	0.425

REFLECTIVITY DATA

Description: Paint

Whitewash applied to serpentine wall rock.

Top readings on dirty unwashed surface.

Dust accumulation = 2+ a.

Bottom readings on clean freshly washed surface.

South Main Mine 3250 L garage

Incident Angle: 0^{o} Tilt Angle: -

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.360
σ = 0.095

$\bar{R}$ = 0.786
σ = 0.088

		Off Angle				
		10^{o}	15^{o}	20^{o}	25^{o}	30^{o}
Read Angle	0^{o}	0.251 0.624	0.317 0.768	0.363 0.654	0.219 0.882	0.479 -
	45^{o}	0.479 0.804	0.191 0.654	0.302 0.804	0.468 0.823	0.398 -
	90^{o}	0.417 0.842	0.479 0.842	0.324 0.701	0.309 0.734	0.204 0.786
	135^{o}	0.372 0.882	0.339 0.786	0.389 0.823	0.363 0.768	- -
	180^{o}	0.457 0.685	0.224 0.902	- -	- -	- -
	225^{o}	0.603 0.786	0.479 0.804	0.363 0.902	0.355 0.654	0.372 0.639
	270^{o}	0.240 0.734	0.381 0.786	0.468 0.923	0.372 0.823	0.372 0.823
	315^{o}	0.389 0.862	0.398 0.583	0.191 0.786	0.289 0.823	0.355 0.804
	$\bar{R}_x$	0.401	0.351	0.343	0.339	0.363
	$\bar{R}_x$	0.777	0.766	0.799	0.787	0.806

REFLECTIVITY DATA

Description: Paint

Whitewash, both

Dirty and fresh clean surfaces

Clean surface 70% of field - top reading

Dirty surface 30% of field - bottom reading

Falconbridge Mine #5 shaft 2800 level Charging station

Incident Angle: 0^{o} Tilt Angle: 0^{o}

Colour Temperature: 2360 K tungsten filament

$\bar{R}$ = 0.894
σ = 0.085
$\bar{R}$ = 0.620
σ = 0.092

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	0.980 0.632	0.834 0.526	0.957 0.662	0.957 0.564	0.936 0.693
45°	0.980 0.551	0.693 0.778	0.796 0.618	0.834 0.618	0.834 0.632
90°	0.936 0.647	0.980 0.693	0.936 0.418	0.957 0.618	0.957 0.693
135°	0.980 0.662	0.914 0.760	0.936 0.678	0.778 0.538	- -
180°	0.914 0.693	0.957 0.526	- -	- -	- -
225°	0.980 0.662	0.957 0.647	0.957 0.778	0.778 0.618	0.815 0.618
270°	0.834 0.678	0.778 0.364	0.980 0.491	0.778 0.590	0.957 0.632
315°	0.957 0.632	0.778 0.604	0.743 0.514	0.893 0.538	0.936 0.743
$\bar{R}_x$	0.945	0.861	0.901	0.854	0.906
$\bar{R}_x$	0.645	0.612	0.594	0.583	0.668

REFLECTIVITY DATA

Description: Paint

Dirty whitewashed surface

Flin Flon Mine, H.B.M.& S. South Main

3250 Shifter's Office

Incident Angle: 0° Tilt Angle: 0°

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.495

σ = 0.056

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	0.420	0.450	0.493	0.541	0.517
45°	0.517	0.567	0.471	0.450	0.493
90°	0.471	0.505	0.482	0.529	0.482
135°	0.450	0.580	0.517	0.471	-
180°	0.567	0.493	-	-	-
225°	0.593	0.593	0.493	0.450	0.461
270°	0.517	0.482	0.461	0.471	0.410
315°	0.593	0.580	0.383	0.482	0.392
$\bar{R}_x$	0.516	0.531	0.471	0.485	0.459

REFLECTIVITY DATA

Description: Paint

Silver, metallic, 1+ a, clean, dry

Specular, bubbly, applied to shotcrete surface

Strathcona Mine 2900 Lunchroom Wall

Incident Angle: 0° Tilt Angle: -

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.481

σ = 0.080

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	0.427	0.486	0.501	0.365	0.432
45°	0.662	0.509	0.486	0.521	0.542
90°	0.698	0.526	0.511	0.462	0.391
135°	0.469	0.542	0.548	0.518	-
180°	0.447	0.539	-	-	-
225°	0.599	0.538	0.438	0.411	0.395
270°	0.411	0.419	0.460	0.402	0.406
315°	0.611	0.458	0.373	0.447	0.370
$\bar{R}_x$	0.540	0.502	0.474	0.447	0.423

REFLECTIVITY DATA

Description: Paint

Yellow paint on metallic victaulic pipe coupling.

Trade name Couplox A

Incident Angle: 0^{o} Tilt Angle: -

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.464

σ = 0.065

		Off Angle				
		10^{o}	15^{o}	20^{o}	25^{o}	30^{o}
Read Angle	0^{o}	0.362	0.397	0.561	0.548	0.379
	45^{o}	0.416	0.406	0.370	0.466	0.488
	90^{o}	0.456	0.561	0.488	0.488	0.416
	135^{o}	0.523	0.466	0.587	0.466	-
	180^{o}	0.435	0.488	-	-	-
	225^{o}	0.416	0.477	0.466	0.416	0.388
	270^{o}	0.500	0.523	0.425	0.466	0.388
	315^{o}	0.416	0.561	0.587	0.370	0.523
	$\bar{R}_x$	0.441	0.485	0.498	0.460	0.430

REFLECTIVITY DATA

Description: Paint

Yellow plastic cap lamp battery

Incident Angle: 0^o Tilt Angle: 0^o

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.804

σ = 0.085

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	0.884	0.702	0.806	0.864	0.655
45°	0.626	0.864	0.788	0.735	0.686
90°	0.926	0.926	0.884	0.788	0.719
135°	0.806	0.864	0.788	0.884	-
180°	0.655	0.926	-	-	-
225°	0.735	0.884	0.825	0.844	0.825
270°	0.864	0.844	0.864	0.884	0.702
315°	0.844	0.735	0.864	0.752	0.702
$\bar{R}_x$	0.792	0.843	0.831	0.822	0.715

REFLECTIVITY DATA

Description: Safety Hat

Brown miner's cap 20 +a

Incident Angle: 0° Tilt Angle: –

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.099

σ = 0.021

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	0.107	0.089	0.091	0.109	0.112
45°	0.089	0.074	0.072	0.085	0.177
90°	0.097	0.107	0.102	0.137	0.117
135°	0.109	0.128	0.083	0.091	–
180°	0.109	0.069	–	–	–
225°	0.104	0.087	0.089	0.104	0.087
270°	0.087	0.091	0.085	0.093	0.109
315°	0.107	0.109	0.107	0.104	0.055
$\bar{R}_x$	0.101	0.094	0.090	0.103	0.110

REFLECTIVITY DATA

Description: Safety Hat

Miner's cap, white, new, M.S.A.

Incident Angle: 0° Tilt Angle: -

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R} = 0.957$

$\sigma = 0.101$

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	0.908	0.887	1.091	1.066	0.950
45°	0.867	0.908	0.908	0.867	1.091
90°	0.828	1.042	0.908	0.950	0.972
135°	1.066	1.042	0.908	0.867	-
180°	0.867	0.887	-	-	-
225°	1.143	1.042	0.908	0.867	0.867
270°	1.091	0.887	1.091	0.867	1.091
315°	0.929	0.867	1.196	0.847	0.867
$\bar{R}_x$	0.962	0.945	1.001	0.904	0.973

REFLECTIVITY DATA

Description: Kodak Test Card

Catalogue No. 1527795, grey surface

Incident Angle: 0° Tilt Angle: 0°

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.250

σ = 0.036

	Off Angle				
Read Angle	10°	15°	20°	25°	30°
0°	0.313	0.275	0.237	0.221	0.193
45°	0.305	0.250	0.243	0.221	0.214
90°	0.295	0.276	0.257	0.241	0.193
135°	0.288	0.257	0.232	0.214	-
180°	0.295	0.263	-	-	-
225°	0.288	0.266	0.232	0.224	0.193
270°	0.299	0.296	0.272	0.237	0.195
315°	0.288	0.266	0.237	0.234	0.200
$\bar{R}_x$	0.296	0.269	0.244	0.227	0.198

REFLECTIVITY DATA

Description: Wood

Mine ladder, 2" x 4" dry spruce

Smooth cut parallel to grain. Clean surface.

Strathcona Mine

Incident Angle: 0° Tilt Angle: 0°

Colour Temperature: 2360 K tungsten filament M.I.

$\bar{R} = 0.396$

$\sigma = 0.059$

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	-	-	-	-	0.425
45°	-	-	0.392	-	-
90°	-	0.414	-	-	0.368
135°	-	-	-	0.383	-
180°	0.486	-	-	-	-
225°	-	-	0.466	-	-
270°	-	-	-	0.424	-
315°	0.490	0.480	-	-	-
$\bar{R}_x$	0.488	0.447	0.429	0.404	0.397

REFLECTIVITY DATA

Description: Wood

Bark off dry spruce logs

Logs used as backfill retaining wall.

Strathcona Mine

Incident Angle: 0° Tilt Angle: -

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.131

σ = 0.029

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	0.133	0.171	0.130	0.175	0.163
45°	0.133	0.103	0.160	0.133	0.175
90°	0.133	0.105	0.175	0.124	0.142
135°	0.130	0.105	0.163	0.084	-
180°	0.101	0.101	-	-	-
225°	0.149	0.127	0.084	0.136	0.149
270°	0.142	0.124	0.139	0.101	0.075
315°	0.084	0.136	0.156	0.124	0.149
$\bar{R}_x$	0.126	0.122	0.144	0.125	0.142

REFLECTIVITY DATA

Description: Wood

2" x 4" dry spruce

Mine ladder,

Rough cut across grain, clean surface, dry

Top reading with S.I.
Bottom reading with M.I. on different sample.

Strathcona Mine

Incident Angle: 0^o Tilt Angle: 0^o

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.386
σ = 0.034

$\bar{R}$ = 0.391
σ = 0.032

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	0.334 0.449	0.367 –	0.327 –	0.319 –	0.358 –
45°	0.411 –	0.393 –	0.367 0.397	0.358 0.381	0.402 –
90°	0.375 –	0.319 –	0.421 –	0.375 –	0.384 0.353
135°	0.411 –	0.367 0.421	0.421 –	0.411 –	– –
180°	0.411 –	0.375 0.404	– –	– –	– –
225°	0.375 0.413	0.402 –	0.451 0.385	0.431 –	0.384 –
270°	0.441 –	0.402 –	0.451 –	0.384 –	0.375 0.347
315°	0.367 –	0.358 –	0.421 –	0.375 0.363	0.375 –
$\bar{R}_x$	0.391	0.373	0.408	0.379	0.380
$\bar{R}_x$	0.431	0.412	0.391	0.372	0.350

REFLECTIVITY DATA

Description: Wood

2" x 4" dry spruce

Mine ladder

Rough cut across grain, clean surface, dry

Strathcona Mine

Incident Angle: 15° Tilt Angle: 0°

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.322

σ = 0.035

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	0.295	0.362	0.281	0.281	0.288
45°	0.309	0.295	0.323	0.316	0.295
90°	0.371	0.407	0.380	0.371	0.295
135°	0.362	0.354	0.338	0.295	-
180°	0.281	0.309	-	-	-
225°	0.316	0.281	0.288	0.281	0.316
270°	0.380	0.354	0.301	0.338	0.330
315°	0.346	0.354	0.301	0.295	0.295
$\bar{R}_x$	0.333	0.340	0.316	0.311	0.303

REFLECTIVITY DATA

Description: Wood

2" x 4" dry spruce

Mine ladder

Rough cut across grain, clean surface, dry.

Strathcona Mine.

Incident Angle: 30^{o} | Tilt Angle: 0^{o}

Colour Temperature: 2360 K tungsten filament | S.E.I.

$\bar{R}$ = 0.301

σ = 0.039

	Off Angle				
Read Angle	10^{o}	15^{o}	20^{o}	25^{o}	30^{o}
0^{o}	0.207	0.273	0.261	0.261	0.207
45^{o}	0.273	0.329	0.321	0.329	0.273
90^{o}	0.273	0.386	0.344	0.329	0.329
135^{o}	0.329	0.321	0.329	0.329	-
180^{o}	0.261	0.314	-	-	-
225^{o}	0.336	0.261	0.307	0.255	0.329
270^{o}	0.300	0.321	0.314	0.329	0.329
315^{o}	0.329	0.273	0.280	0.329	0.261
$\bar{R}_x$	0.288	0.310	0.308	0.309	0.288

REFLECTIVITY DATA

Description: Wood

2" x 4" dry spruce

Mine ladder

rough cut across grain, clean surface, dry

Strathcona

Incident Angle: 45°   Tilt Angle: 0°

Colour Temperature: 2360 K tungsten filament   S.E.I.

$\bar{R}$ = 0.304

σ = 0.030

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	0.320	0.292	0.254	0.242	0.266
45°	0.312	0.284	0.260	0.292	0.242
90°	0.312	0.320	0.335	0.343	0.292
135°	0.320	0.260	0.260	0.292	-
180°	0.272	0.359	-	-	-
225°	0.327	0.327	0.320	0.292	0.312
270°	0.320	0.320	0.320	0.320	0.312
315°	0.312	0.312	0.327	0.327	0.359
$\bar{R}_x$	0.312	0.309	0.297	0.301	0.297

REFLECTIVITY DATA

Description: Metal

Rusted metallic victaulic pipe coupling for 4" line.

Incident Angle: 0° Tilt Angle: -

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.135

σ = 0.017

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	0.127	0.116	0.116	0.130	0.127
45°	0.143	0.136	0.111	0.113	0.136
90°	0.143	0.176	0.136	0.143	0.130
135°	0.146	0.130	0.149	0.119	-
180°	0.143	0.143	-	-	-
225°	0.113	0.143	0.160	0.136	0.139
270°	0.172	0.136	0.127	0.111	0.119
315°	0.180	0.143	0.124	0.136	0.121
$\bar{R}_x$	0.146	0.140	0.132	0.127	0.129

REFLECTIVITY DATA

Description: Metal

Polished metallic victaulic pipe coupling

Incident Angle: 0° Tilt Angle: -

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.137

σ = 0.070

		Off Angle				
		10°	15°	20°	25°	30°
Read Angle	0°	0.212	0.180	0.193	0.227	0.180
	45°	0.249	0.114	0.130	0.080	0.048
	90°	0.227	0.133	0.137	0.092	0.067
	135°	0.273	0.193	0.109	0.058	-
	180°	0.254	0.122	-	-	-
	225°	0.127	0.137	0.080	0.054	0.048
	270°	0.153	0.133	0.109	0.090	0.042
	315°	0.216	0.168	0.157	0.097	0.043
	$\bar{R}_x$	0.214	0.148	0.131	0.100	0.071

REFLECTIVITY DATA

Description: Cement

Shotcrete

White to grey, porous, clean 2+ a, dry

Strathcona Mine 2900 Lunchroom wall

Incident Angle: 0^{o} Tilt Angle: -

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.433

σ = 0.053

		Off Angle				
		10^{o}	15^{o}	20^{o}	25^{o}	30^{o}
Read Angle	0^{o}	0.421	0.572	0.401	0.397	0.400
	45^{o}	0.486	0.372	0.401	0.389	0.535
	90^{o}	0.454	0.429	0.437	0.369	0.395
	135^{o}	0.410	0.396	0.361	0.374	-
	180^{o}	0.489	0.489	-	-	-
	225^{o}	0.369	0.461	0.475	0.465	0.384
	270^{o}	0.361	0.486	0.433	0.504	0.455
	315^{o}	0.429	0.481	0.392	0.510	0.405
	$\bar{R}_x$	0.427	0.461	0.414	0.430	0.429

REFLECTIVITY DATA

Description: Fibrin

Synthetic material used to replace burlap to line manways, mousetraps, etc. prior to backfill pour, slightly specular, clean, dry.

Falconbridge Mine

Incident Angle: 0° Tilt Angle: 0°

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.189

σ = 0.045

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	0.225	0.241	0.183	0.231	0.124
45°	0.159	0.196	0.183	0.145	0.145
90°	0.290	0.205	0.196	0.163	0.163
135°	0.290	0.145	0.171	0.152	-
180°	0.225	0.159	-	-	-
225°	0.231	0.171	0.183	0.171	0.130
270°	0.201	0.210	0.159	0.183	0.149
315°	0.277	0.231	0.196	0.152	0.183
$\bar{R}_x$	0.237	0.195	0.182	0.171	0.149

REFLECTIVITY DATA

Description: Air Ducting

flat orange

Strathcona Mine

Incident Angle: 0° Tilt Angle: 0°

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.359

σ = 0.033

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	0.358	0.350	0.326	0.366	0.358
45°	0.358	0.375	0.411	0.358	0.342
90°	0.383	0.350	0.342	0.411	0.350
135°	0.350	0.430	0.334	0.420	-
180°	0.383	0.271	-	-	-
225°	0.342	0.342	0.342	0.342	0.326
270°	0.342	0.342	0.319	0.383	0.411
315°	0.383	0.411	0.342	0.342	0.334
$\bar{R}_x$	0.362	0.359	0.345	0.375	0.354

REFLECTIVITY DATA

Description: Oilers - inside pants leg

Incident Angle: 0° Tilt Angle: 0°

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.436

σ = 0.038

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	0.535	0.477	0.425	0.435	0.456
45°	0.445	0.370	0.445	0.425	0.435
90°	0.425	0.425	0.435	0.488	0.435
135°	0.425	0.445	0.435	0.415	-
180°	0.445	0.435	-	-	-
225°	0.548	0.466	0.425	0.477	0.415
270°	0.435	0.435	0.425	0.425	0.362
315°	0.406	0.370	0.397	0.406	0.445
$\bar{R}_x$	0.458	0.428	0.427	0.439	0.425

REFLECTIVITY DATA

Description: Mucking Boots

Black corrugated surface caked with dry mud

Incident Angle: 0° Tilt Angle: 0°

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.145

σ = 0.019

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	0.127	0.171	0.119	0.149	0.143
45°	0.156	0.156	0.127	0.149	0.146
90°	0.124	0.180	0.188	0.139	0.143
135°	0.143	0.149	0.184	0.143	-
180°	0.124	0.149	-	-	-
225°	0.153	0.171	0.127	0.136	0.124
270°	0.156	0.143	0.139	0.113	0.113
315°	0.168	0.149	0.160	0.153	0.116
$\bar{R}_x$	0.144	0.158	0.149	0.140	0.131

REFLECTIVITY DATA

Description: Black Rubber Boots

(smooth surface)

Incident Angle: 0^{o} Tilt Angle: 0^{o}

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.058

σ = 0.012

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	0.061	0.051	0.057	0.061	0.042
45°	0.049	0.065	0.058	0.057	0.067
90°	0.051	0.059	0.042	0.038	0.038
135°	0.077	0.075	0.053	0.075	-
180°	0.084	0.043	-	-	-
225°	0.058	0.052	0.071	0.048	0.052
270°	0.057	0.058	0.058	0.049	0.057
315°	0.049	0.061	0.080	0.054	0.071
$\bar{R}_x$	0.061	0.058	0.060	0.055	0.054

REFLECTIVITY DATA

Description: Red Reflective Tape

(3M Scotchlite)

Incident Angle: 0° Tilt Angle: 0°

Colour Temperature: 2360 K tungsten filament S.E.I.

$\bar{R}$ = 0.467

σ = 0.221

Read Angle	Off Angle 10°	15°	20°	25°	30°
0°	0.603	0.502	0.355	0.289	0.246
45°	0.872	0.617	0.355	0.282	0.219
90°	0.852	0.576	0.316	0.224	0.282
135°	0.742	0.447	0.347	0.269	-
180°	0.872	0.447	-	-	-
225°	0.814	0.563	0.372	0.282	0.282
270°	0.892	0.563	0.501	0.339	0.295
315°	0.892	0.437	0.380	0.276	0.214
$\bar{R}_x$	0.817	0.519	0.375	0.280	0.256