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HISTORICAL RESEARCH REPORT

Research Report TM/80/08
1981

Visual requirements and lighting standards in mining operations. Final report on CEC Contract 6245-11/8/048

Best CF, Graveling RA, Graves RJ, Leamon TB, Simpson GC, Sims MT

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FINAL REPORT ON CEC
CONTRACT 6245-11/8/048

Visual Requirements and Lighting Standards in Mining Operations

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G C Simpson
M T Sims

April 1981

This report is made primarily from the point of view of ergonomics. The authors are not in a position to be able to take full account of mining, engineering or other requirements. It is, therefore, recognised that it may not be practicable to implement the ergonomics recommendations in full, but any possible breaches of the law relating to health and safety revealed by the report must, of course, be avoided.

VISUAL REQUIREMENTS AND LIGHTING STANDARDS IN MINING OPERATIONS

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CONTENTS

Page No.

LIST OF TABLES

LIST OF FIGURES

X.

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SUMMARY

The project reported assessed current levels of illumination in the British coalmining industry and the manner in which the design, layout and maintenance of lighting systems affected the level and distribution of this illumination within working areas. Surveys were carried out to determine the visual requirements for a wide range of mining tasks, and the existing illumination levels were evaluated within the context of these requirements. This evaluation showed the extensive benefits obtained from the use of mains lighting. The design and layout of lighting systems was found to have a considerable effect on light distribution and the consequent adequacy of lighting for task requirements. Several recommendations are made regarding system design for optimum light distribution. In particular, the location of mains luminaires parallel to the roadway on alternate walls considerably improved light distribution and markedly reduced the accumulation of light-obscuring dust in comparison to luminaires mounted at right angles to the roadway.

Where mains lighting was not installed, individual miners were dependent upon the light provided by their personal cap lamp. Light levels from this were adequate for close work, but the distribution characteristics of the cap lamp beam produced several effects which involved potential problems for satisfactory task performance. Two of these were studied in more detail and one of them, peripheral vision, was found to be significantly improved by an ambient light level of 5 lux. A similar light level was found to be a minimum requirement for the light from locomotive headlamps at a distance of 60 metres.

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1. INTRODUCTION

The Mines and Quarries Act (1954) included guidelines for the provision of lighting in underground locations such that 'suitable and sufficient' artificial lighting should be provided, although no indication of what constituted a suitable level was provided. However, various authors have produced recommendations for lighting levels for underground locations. For example, Bell (1965), in describing a design procedure for colliery lighting, adopted a standard requirement of 10 lux in working roadways rising to 60 lux in certain areas (e.g. mine-car loading areas). Bell and Neill (1968) recommended a general level of illumination of 10 lux for the coal face based on their personal experiences of mine lighting, with additional illumination for specific tasks generally provided by the cap lamp, producing levels of up to 40 lux. More recently, Menne (1980) examined a number of face activities and recommended an average face lighting level of 40 - 50 lux. The National Coal Board Standards (NCB, 1974) did not provide any guidelines for face lighting. The recommended minima for other underground areas ranged from 2.5 lux for roadways where men regularly walk past operating machinery (and similar operations), through 30 lux in areas where conveyors load into mine-cars, to 150 lux in garage inspection areas.

An additional important factor in lighting practice is the distribution of light. Roberts (1955) referred to the concept of a 'diversity ratio', being the ratio between maximum and minimum light levels in a given area. Bell (1965) subsequently recommended a maximum diversity ratio of 5:1 based on "economy and experience". Menne (op cit) did not recommend any actual values, although he emphasised the need to consider the distribution of light, concluding that there must be a "high degree of uniformity". Although the National Coal Board recommendations (op cit) do not contain any definitive statement regarding diversity ratios, they do draw attention to the need to consider the distribution in assessing the "quality" of lighting. It was generally found that literature on lighting such as that published by Hopkinson (1940, 1941, 1950 and 1951), Blackwell (1946 and 1949), Stevens (1951) and Weston (1961) assessed the visual requirements of tasks on detailed principles of task vs. background contrast, visual acuity demanded, etc.. However, the mobile nature of many mining tasks and the consequent wide variation in visual conditions, together with the increased complexity of many tasks referred to earlier, may preclude the applicability of such techniques.

The present project was established to examine current standards of illumination and the manner in which the design, layout and maintenance of lighting systems affected the level and distribution of illumination within working areas. Extensive surveys were therefore carried out to provide information on the levels and distribution of illumination and the extent to which these were modified by variations in colliery lighting and maintenance practices. Particular emphasis was placed upon the extent to which visual requirements have been altered over the last 20 years by the wide-scale introduction of mechanisation, resulting in an increase in the visual distances involved for some tasks and the general increase in task complexity. The illumination data obtained were evaluated in comparison to the existing recommendations and the visual requirements for workers within specific areas. These requirements were determined by detailed task analysis, structured interviews and a study of miners' visual abilities.

Some aspects of visual performance in mining were selected for more detailed studies. These investigated features of the illumination provided by the general issue cap lamp, which were identified during the course of the lighting surveys and task analyses. Other specific studies examined aspects such as the headlamps available for locomotives and the various reflective materials provided for protective clothing to improve wearer visibility.

A subsequent section details the development of a practical method of establishing guidelines for lighting practice based on subjective assessment, and its application to the illumination of complex process areas.

All lighting terms, e.g. luminaires, lux, are used as defined in the Code of the Illuminating Engineering Society (IES) (IES, 1977).

2. LIGHTING PRACTICE UNDERGROUND

Light levels and current lighting policy were examined at a variety of locations within four collieries. Attention was paid to the effect of type and orientation of luminaires on these levels.

2.1 Light Levels

2.1.1 Fixed Mains Lighting Light levels from fixed mains lighting were recorded at pit bottoms, roadways, junctions, transfer points and motor houses. Many areas of the collieries surveyed had no mains lighting, including most gate roads, and many supply roads. The rip area of face ends was not lit, but luminaires were installed on the power supply equipment normally situated 8 - 10 m outbye of the face, and data on face ends refer to these light levels. Data were also collected on coal faces at three of the four collieries. This proportion is not representative of British coal mines generally, where out of 670 faces currently being worked, 22 have mains lighting. The collieries had been specifically selected because of their use of mains lighting on faces. Table 1 shows means and standard deviations of light levels obtained beneath and half-way between luminaires at each of these locations.

TABLE 1

Means and Standard Deviations of Light Levels obtained at Underground Locations

	Light Levels (lux) $\bar{x} \pm SD$	
	Beneath Luminaires	Between Luminaires
Pit Bottoms	77.0 ± 44.4	28.8 ± 14.5
Junctions	48.9 ± 24.8	24.8 ± 25.3
Motor Houses	82.0 ± 16.9	52.0 ± 22.9
Transfer Points	41.2 ± 22.6	20.0 ± 11.1
Roadways	45.2 ± 25.4	16.8 ± 14.7
Face Ends	6.1 ± 0.9	3.6 ± 0.7
Faces	12.3 ± 12.8	2.3 ± 2.0

With the exception of motorhouses and general roadway lighting, the mean values recorded were either less than or approximately the same as the minimum values recommended by the National Coal Board (National Coal Board, op cit). This did not apply to face ends and faces for which no recommendations were made.

2.1.2 Machine Lighting Surveys of light levels provided by machine lighting included all lamps currently certified for underground use. Machines equipped with lamps included all locomotives and some machines used at face ends.

Illumination levels provided by the lamps were recorded at 10.0 m intervals up to a distance of 60.0 m. The results are shown in Table 2.

TABLE 2

Light Levels provided by Headlamps certified for use on Machines Underground (lux)
(The levels were recorded at 10 m intervals at the centre of the beam)

Lamp	Distance of Measurement from Lamp Lens (metres)					
	10	20	30	40	50	60
A	32.4	8.4	3.8	2.2	1.4	1.0
B	15.3	2.9	2.0	0.8	0.6	0.5
C	6.3	1.5	0.9	0.6	0.5	0.4
D	8.7	1.9	1.0	0.4	0.3	0.2
E*	1656.3	407.2	179.4	96.6	63.4	43.5
F	160.3	55.1	23.7	13.6	8.4	5.9

* Lamp E is a new luminaire which is not currently fitted to any machines underground.

2.1.3 Cap Lamp Lighting Three types of reflectors are available for the cap lamps used by the National Coal Board. These are:

a) 'Diffused' - which give a maximum spread of light.

b) 'Soft beam' - which combine a high degree of diffusion with a beam of fairly high intensity.

c) **Specular** - which give little spread of light, concentrating most of the light output into a high intensity beam.

Neill (1967) produced polar curves (patterns of light distribution) for these three types of reflector and these curves are reproduced in Figure 1.

There has been a trend in recent years for miners to request cap lamps fitted with specular reflectors providing a longer effective viewing distance.

Table 3 shows the light levels provided by a sample of these lamps along the line of the beam from the cap lamp glass and laterally from the light beam centre.

TABLE 3

The Means and Standard Deviations of Light Levels produced by a sample of 10 Cap Lamps with Specular Reflectors

Distance from Lamp Glass	Light Levels (lux)			
	Lateral Distance from Centre of Beam (m)			
	Centre	0.25	0.5	0.75
0.25	8600 ± 1408	10 ± 1.6	2.5 ± 0.4	0.5 ± 0.1
0.5	3000 ± 491	2.5 ± 0.4	1.5 ± 0.2	-
1.0	800 ± 131	7.5 ± 1.2	2.5 ± 0.4	0.5 ± 0.1
5.0	32 ± 5.2	0.5 ± 0.1	-	-
10.0	6.0 ± 1.0	-	-	-
15.0	2.5 ± 0.4	-	-	-
20.0	1.0 ± 0.2	-	-	-
25.0	0.5 ± 0.1	-	-	-

2.2 <u>Lighting Installation and How They Affect Light Levels</u>

2.2.1 Fixed Mains Lighting A number of types of luminaire were used in mains lighting systems underground. The areas in which they were used were divided into three main locations:

a) All areas outbye of gate roads (general);

b) Face ends;

c) Faces.

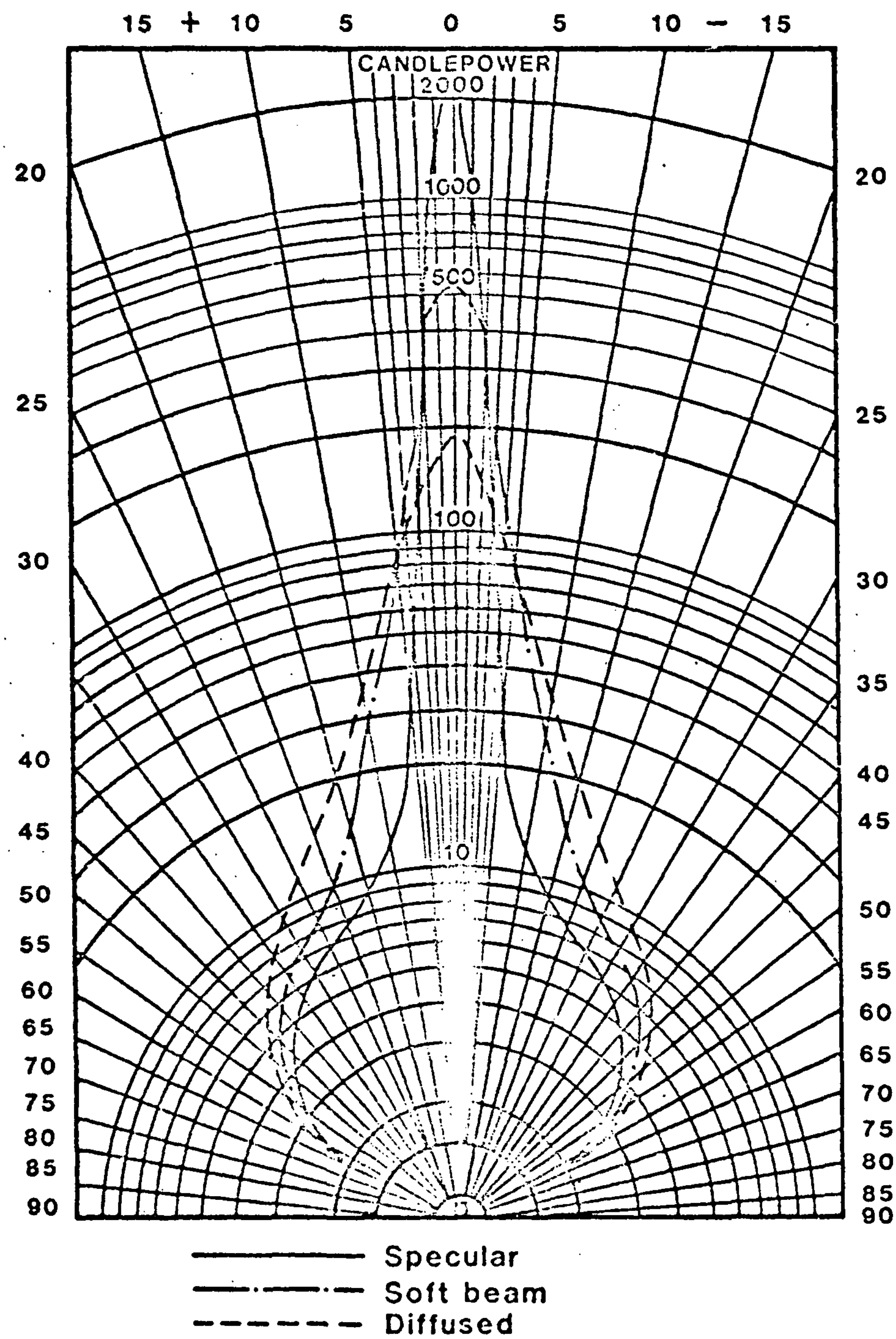


FIGURE 1 - Polar Curves showing Light Distribution for the Three Types of Cap Lamp Reflectors

2.2.1.1 General Lighting

(a) Luminaires Three types of luminaire were identified during surveys of all areas outbye of gate roads. Table 4 details these luminaires and the light output provided from them.

TABLE 4

Three Luminaires used in General Colliery Lighting Underground with Light Outputs

Luminaire	Light Output (Manufacturers' Figures)
Tubular Fluorescent	2,500 - 4,700 lumens depending on tube
GLS Tungsten Filament	1960 lumens (150 watt)
MBF/U Mercury Discharge	2480 lumens (80 watt) 3875 lumens (125 watt)

(b) Orientation and Location The variation in light levels listed in Table 1 (Section 2) was a function of luminaire orientation and distances between luminaires. For example, in roadways three orientations of fluorescent luminaires were seen as illustrated in Figure 2. These were:-

a) In line with the roadway;
b) At right angles to the roadway;
c) Placed on the walls on alternate sides.

The centres of the luminaires were positioned at 12.0 m intervals in all three cases.

Light levels between luminaires which were in line with the roadway (a) were low relative to levels produced by other orientations. The ratio of light levels beneath lamps to those between was 10.6:1, 5.76:1 and 2.89:1 for orientations (a), (b) and (c) respectively. The high variability in orientation (a) was due to the relatively low light output at the ends of fluorescent tubes. Luminaires in orientation (b) produced improved distribution along the line of the roadway but with lower light

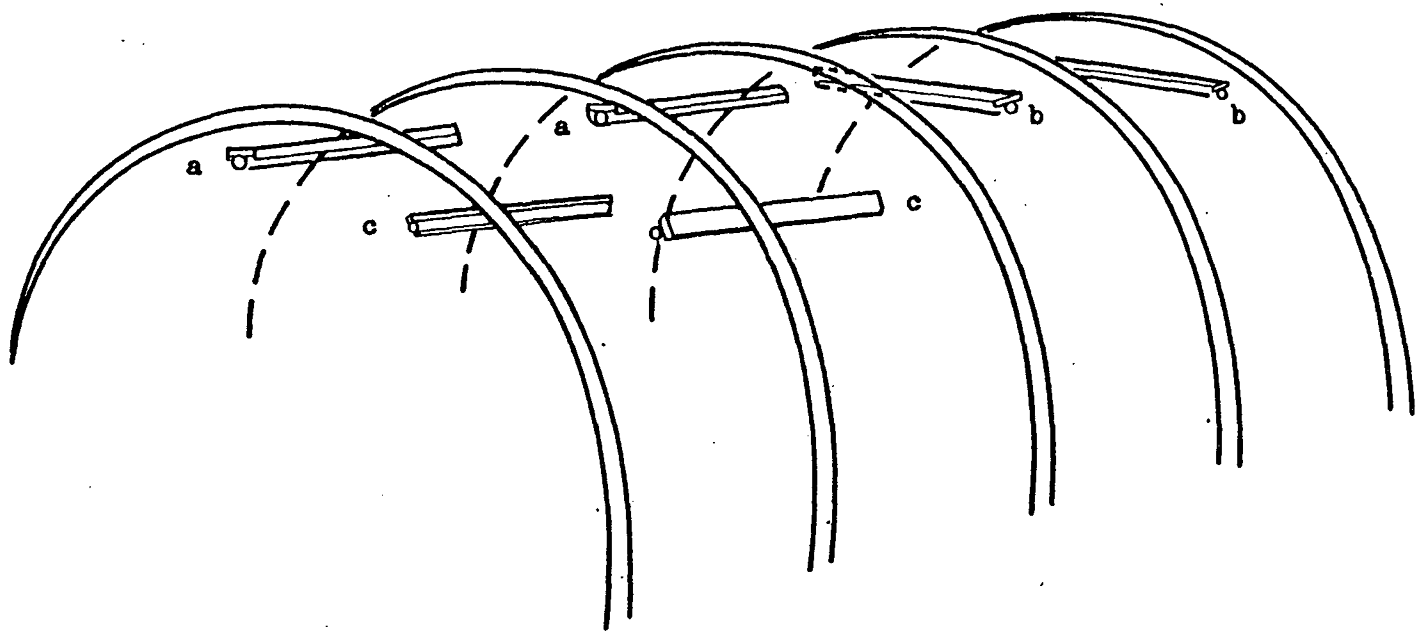


FIGURE 2 - The Various Orientations of Tubular Fluorescent Luminaires with respect to Roadways

(a = in line with roadway; b = across roadway; c = on alternate sides of roadway)

FIGURE 2.

levels on the walls, i.e. opposite the ends of lamps. Orientation (c) provided the most even distribution of light as demonstrated by the ratios of light levels.

Similar considerations of the need for a uniform distribution of light can be applied to other areas in the colliery (for example, junctions and pit bottoms) although as the size, shape and layout of some of these areas differ widely it is not possible to provide general specifications for luminaire locations. Although light levels varied widely between collieries as demonstrated by the standard deviations shown in Table 1 (Section 2.1.1), the distribution within any specific location tended to be good as indicated by Table 5 which shows the ratio of light levels beneath luminaires to those between luminaires (diversity ratios) for a number of locations within four collieries. Bell (op cit) recommended a maximum diversity ratio of 5:1 and all the values shown in Table 5 are well within this limit.

TABLE 5

Typical Diversity Ratios for a Number of Locations within Four Collieries (Light Levels Beneath and Between Luminaires)

Location / Colliery	Motor Houses	Pit Bottom	Junctions	Transfer Points
A	1.1:1	1.35:1	1.7:1	1.33:1
B	1.9:1	3.0:1	3.0:1	3.0:1
C	1.85:1	1.34:1	2.4:1	1.95:1
E	1.8:1	1.4:1	2.05:1	1.91:1

2.2.1.2 Face Lighting

a) Luminaire Types Two types of luminaire were observed to be used as fixed mains lighting on coal faces. These were:

i) 3 x 4W, tubular fluorescent, flameproof;

and ii) 235 mm, 8 W, tubular fluorescent, intrinsically safe.

Type (i) had a heavy gauge flameproof casing, housing three, 4 watt lamps. Two glass windows were provided in the casing. One faced downwards and the other was at one end of the casing. Type (ii) did not have a protective casing because it was certified as intrinsically safe. Light levels of up to 6.7 lux were recorded beneath the intrinsically safe luminaires while levels of up to 27.0 lux were recorded beneath the more powerful flameproof luminaires (at floor level, 1.5 to 2.0 metres below the luminaires).

b) <u>Location and Orientation</u> Three coal faces with mains lighting were examined. These all had a luminaire on alternate powered supports. The same arrangement was used in lighting the seven other illuminated coal faces at the three collieries visited and is the standard arrangement for illuminating faces, although one prototype system using a luminaire on each powered support is in use. In two of the three lighting systems surveyed, the luminaires were attached to the underside of the roof of the powered support, above the travelway and at right angles to it. On the third, the luminaires were attached vertically to one of the front pair of rear legs on the powered supports. Colliery officials stated that luminaires were sometimes placed parallel to the travelway, between the front two legs of the powered supports. These three orientations are illustrated in Figure 3.

Table 6 shows typical light levels obtained from the two types of luminaire when attached to the travelway roof. The light levels for the flameproof luminaire were obtained from supports where the small end window was directed towards the face. This accounted for the comparatively high light levels recorded on the support controls and onto the floor in front of the supports with this luminaire. Despite this forward-facing window, the light levels on the coal face and the roof were still very low because of shadows cast by the supports. It can be seen that, for both types of luminaire, most of the light output was directed into the travelway, facilitating travel and illuminating the powered support controls. Very little light was provided to illuminate the coal face.

On some supports, the flameproof luminaires had been turned through 180° so that the window was directed away from the face. This had been done by maintenance personnel as very little light was cast onto the rear area of the powered support when the luminaires were in their usual position.

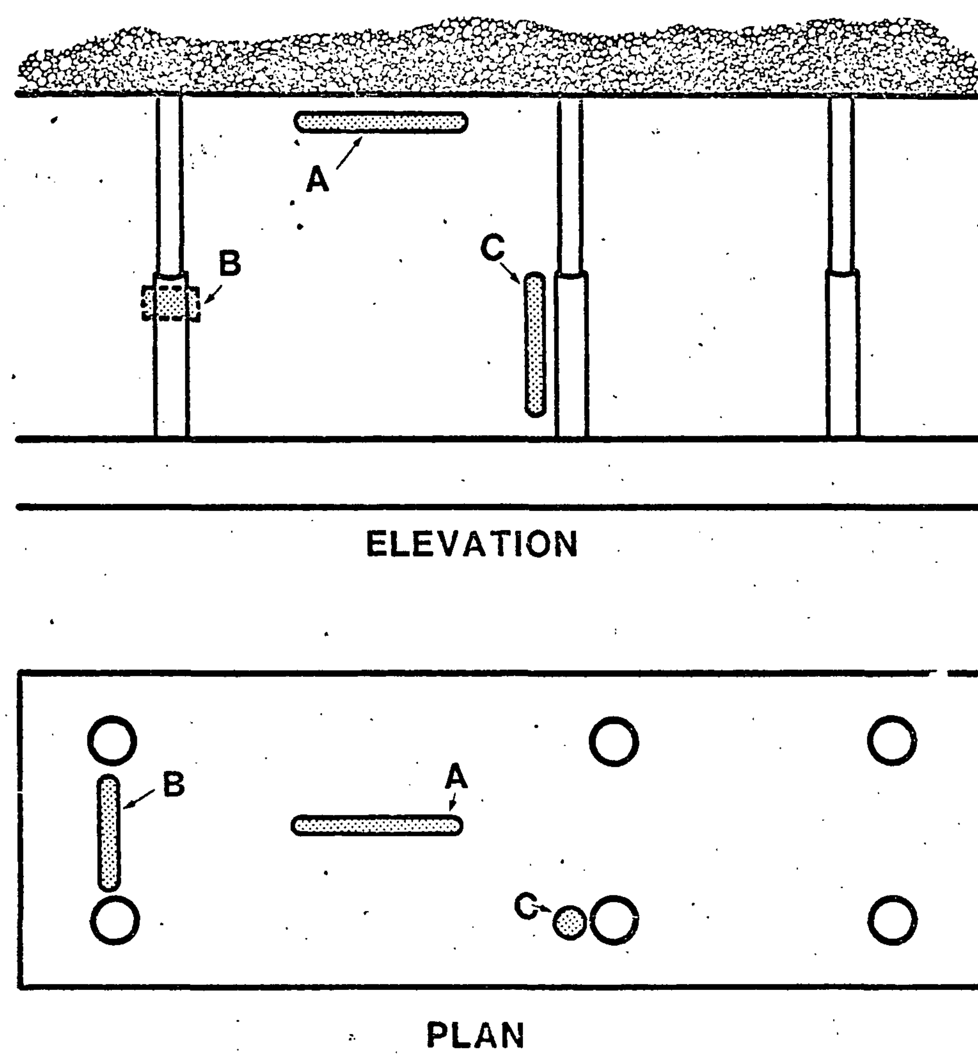


FIGURE 3 - A Plan and Elevation View of a Powered Support with the Three Mounting Positions for Luminaires Illustrated

FIGURE 3.

Level and variability of face lighting is affected by a number of factors including the location of luminaires, and the height and general design of the powered supports. For example, positioning luminaires between the front legs would improve light levels on the areas in front of the supports but would cast heavy shadows of the legs into the travelway.

TABLE 6

Light Levels provided at the Coal Face by Two Types of Face Lighting

Recording Position	Light Level (lux)	
	Intrinsically Safe Luminaires	Flameproof Luminaire
Travelway at floor level:		
Under lamps	14.0	27.0
Between lamps	6.0	9.0
Support controls (between legs) on front legs	3.0	11.0
Coal face	0 - 0.4	0 - 0.5
Roof	0 - 0.2	0 - 0.8
Floor in front of supports	0 - 0.5	0 - 1.5

It was found that little guidance was available on the selection of locations for luminaires. Consequently, a study was carried out to investigate the changes in distribution of light produced by different luminaire locations on powered supports (Section 4.2).

2.2.1.3 <u>Face End Lighting</u>

a) <u>Luminaire Types</u> At the face ends of the collieries studied, mains lighting was provided at the equipment which supplied power for all machinery used at the face and headings, approximately 8 - 10 m outbye. It was not provided at the actual junctions between the gate roads and the face. Three types of luminaires were observed, the 1.5 m, 65 - 80 W, flameproof tubular fluorescent luminaire used for general lighting, a 600 mm, 20 W, flameproof tubular luminaire, and the 235 mm, 8 W, intrinsically safe fluorescent luminaire designed for face lighting.

Only the 600 mm luminaire was specifically designed for face ends and could be used in conjunction with a monorail carriage so that the luminaires could be moved prior to shot-firing. This luminaire was the most commonly seen, whereas the 235 mm luminaire was only observed at one face end.

A typical 10.0 m run of power supply equipment would be illuminated by one 1.5 m luminaire, six 600 mm luminaires or ten 235 mm luminaires, generally providing similar light levels (see Table 1).

b) Location and Orientation All the luminaires used in lighting systems at face ends were suspended above the power supply equipment, parallel to the roadway. Table 7 shows light levels recorded for two of the three systems described. Although the light levels produced immediately beneath the luminaires (on the upper surface of the switchgear) were high (particularly for the 600 mm luminaires which were located very close to the surface), the levels produced on the face of the switchgear where any control gauges are located were much lower. Illumination of the switchgear would be greatly improved by mounting the luminaires in a suitable position to cast more light onto the front surface of any switchgear and transformers. Such repositioning would also produce higher illumination levels in roadway surfaces from available luminaires.

TABLE 7

Light Levels Provided by Two Types of Lighting onto Switchgear in Face Ends

Recording Position	Light Levels (lux)	
	600 mm 20 W	235 mm 8 W
On upper surface of switchgear	860.0	86.0
On face of switchgear	4.2	3.8

2.2.2 Mobile Lighting

2.2.2.1 Machine Headlamps Six types of headlamp shown in Figures 5,6 and 7 are currently available in flameproof forms for use underground. Several of these can be used with a variety of bulbs, producing a wide range of light levels from a single unit. Table 8 shows the headlamps and

TABLE 8

Headlamps, Physical Dimensions and Bulb Options

Headlamp	(A)	(B)	(C)	(D)	(E)	(F)
Size (mm)	280 x 230	185 x 170	270 x 250	260 x 280	220 x 220	310 x 240
Weight (kg)	20.1	7.65	23.45	21.25	14.4	16.75
Bulb Options	H1 55W 12V H3 55W 12V H3 70W 24V	H1 55W 12V H3 55W 12V H3 70W 24V	H1 55W 12V H3 55W 12V H3 70W 24V	36W 12V	H3 55W 12V H3 70W 24V	H3 55W 12V H3 70W 24V

bulb fittings available.

Section 2.1 indicated that large areas of collieries were unlit, including many roadways and headings. Machine-mounted lighting is therefore an important aspect of the underground visual environment, and consequently a detailed study of the lighting characteristics of these headlamps was carried out (Section 4.1).

These headlamps are used on a number of machines, particularly locomotives and heading machines.

a) Headlamps on Locomotives At the time of the study, 1011 locomotives were in use underground, generally having between one and three headlamps (most frequently one). Samples of 16 different locomotives representing 63% of diesel and 72% of electric locomotives were examined. Of these, 94% had headlamps fitted with tungsten filament bulbs, the remainder having quartz halogen bulbs. Seven different locations are used for installing headlamps on the front end of locomotives. Figure 4 shows a typical profile of the front end of a locomotive with the alternative locations indicated and the frequency of use of each location (C Lunnon, National Coal Board, personal communication); the top three locations were the most widely used (70%). The lower locations improve the visibility of obstructions on the floor of a roadway by causing them to cast longer shadows. Headlamp location was included in the study of headlamp lighting characteristics (Section 4.1).

b) Lamps on Heading Machines Machines representative of over 80% of those in use underground were examined. Provision of lighting on them varied tremendously. 30% of machine types observed had no lamps fitted at all, 50% had just front lamps, and 20% had front and rear lamps including one machine with integral white and red lamps at both ends, the appropriate ones being selected automatically by a linkage with the direction controls. Those machines fitted with front lamps had between one and three, with 85% of those machines with front lamps having two. The location and orientation of these lamps was related to function, and is discussed under visual requirements (Section 3.3.3).

2.2.2.2 Cap Lamps The cap lamp was generally worn attached to the safety helmet using the bracket provided. However, where more flexible lighting was required (Section 3.1), the lamp was worn hanging round the miner's neck so the beam could be directed by hand.

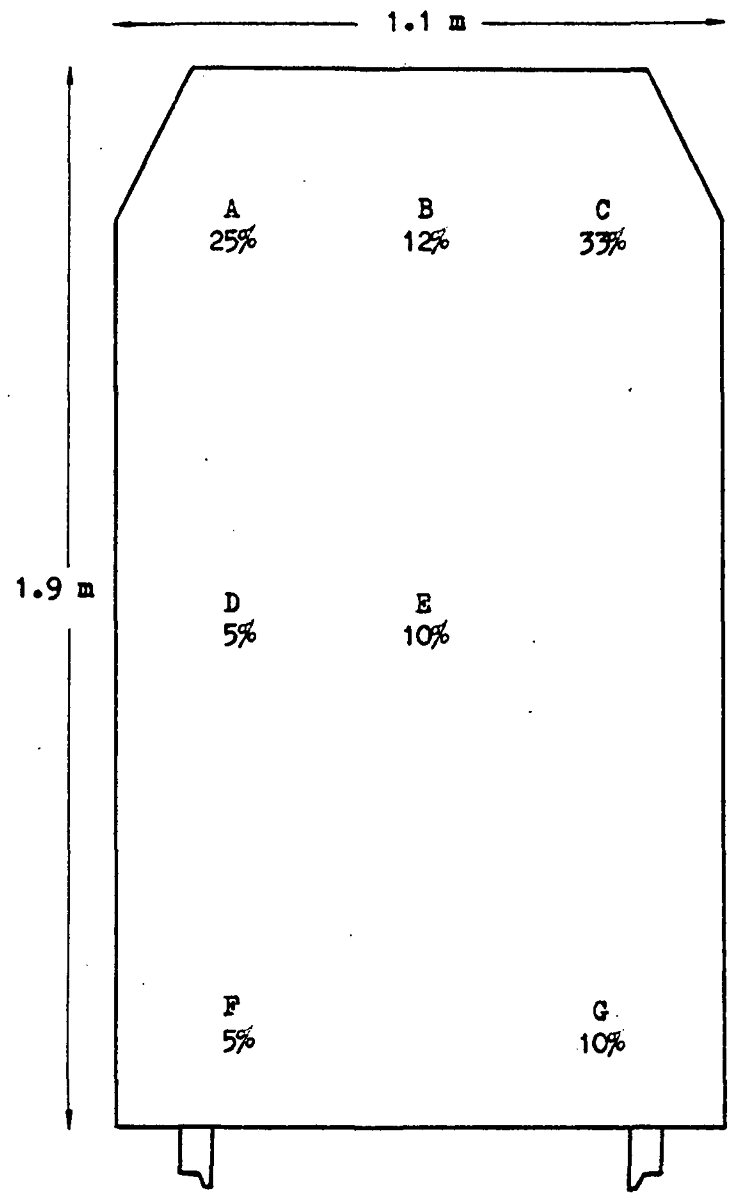


FIGURE 4 - Typical Profile of a Locomotive showing Relative Frequency of Positions for Headlamps

2.3 Luminaire Maintenance and Cleaning

An examination of the effects of proper maintenance and cleaning showed that these factors clearly influenced both the absolute light levels and light level variability.

2.3.1 General Lighting There did not appear to be a policy of regular luminaire cleaning at any colliery visited. The effect this had on light levels tended to vary according to how much dust there was in the atmosphere. For example, in a dusty location, cleaning a single luminaire produced a 100% increase in the light level beneath it whereas, in a cleaner environment, typical improvements were only 8 - 10%. The type of luminaire and its orientation in the roadway also affected how much dust collected on them. Tubular fluorescent luminaires tended to collect less dust than those of a wellglass construction in the same location, and tubular luminaires collected more dust when orientated across the roadway rather than in line with it; another reason for the preferred luminaire orientation described (Section 2.2.1.1).

Luminaire maintenance was generally limited to replacing bulbs or tubes when necessary.

2.3.2 Face Lighting Colliery officials reported that maintenance of intrinsically safe lighting systems was a problem which was tending to restrict the wider use of these systems. For example, unlike the flameproof systems which had heavy gauge armoured cable, the cable used on the intrinsically safe system was relatively thin and comparatively easily snagged and broken when advancing supports. Because of this and other factors, there were likely to be several luminaires not functioning at any one time which contributed to the variations in light levels along the face. It was also reported that, where failure of luminaires occurred frequently, it was not unknown for complete systems to fall into disuse. Cleaning the luminaires was not reported to be a problem.

2.3.3 Face End Lighting No specific maintenance problems were reported for these systems. There was no regular cleaning schedule and similar benefits to those described could be obtained by having one.

2.3.4 Machine Lighting On locomotives, provision of an effective light source is a legal requirement (Health and Safety Executive, 1977) and consequently, headlamp maintenance was included in the monthly overhaul schedule at the underground locomotive garage.

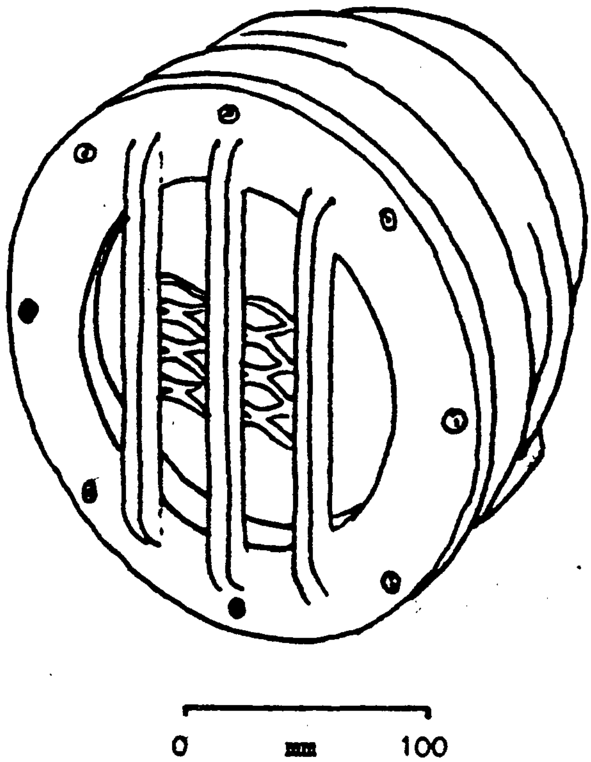
The ease with which the various lamps could be cleaned, or light bulbs replaced, was governed by design features (see Figures 5, 6 and 7). The main obstacle to cleaning the lamp was that the protective grill obstructed the lamp glass. These were in various designs and presented varying levels of difficulty in cleaning the lamps. An additional design problem was the need for specific keys to remove the lamp glass. This made bulb replacement during normal locomotive operations unnecessarily time-consuming. Lamps mounted in positions A and C (Figure 4) were particularly prone to being dislocated by hitting protrusions from roadway walls and roof.

There is no legal requirement for lighting on equipment in headings such as bucket loaders, and no similar maintenance schedules. While the requirement for special tools with which to remove protective covers is necessary for intrinsic safety reasons, this could create difficulties for the routine cleaning and maintenance of lamps. The need for cleaning of lamps was generally greater than on locomotives because of the nature of the working environment.

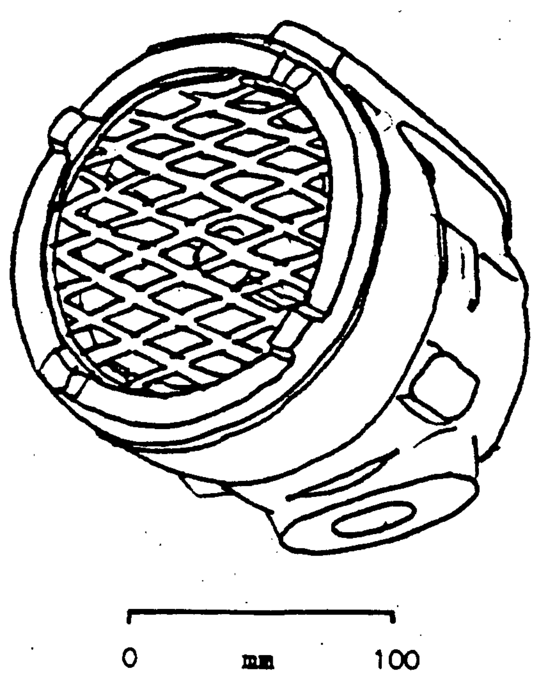
2.3.5 Cap Lamps Cap lamps are regularly checked for physical condition and light output on a scheduled basis. In addition, any fault which occurs between these maintenance checks is reported by the miner allocated that lamp, and rectified, or a replacement issued.

2.4 Other Factors Affecting Light Levels and Distribution

For a given light output in a particular location, light levels and distribution can be enhanced by improving the light reflection of surfaces. Table 9 shows the reflecting powers of surfaces commonly seen underground from which it can be seen that whitewashing a wall can increase its light-reflecting ability by 1800 percent compared to one coated with coal dust. All collieries surveyed made use of whitewash as a cost-effective means of improving lighting performance. Similarly, stone-dusting floors, as well as being a safety measure, markedly improved their reflectivity. Painting machinery, as an aid to general illumination as well as visibility of the object painted, is also a useful exercise as the



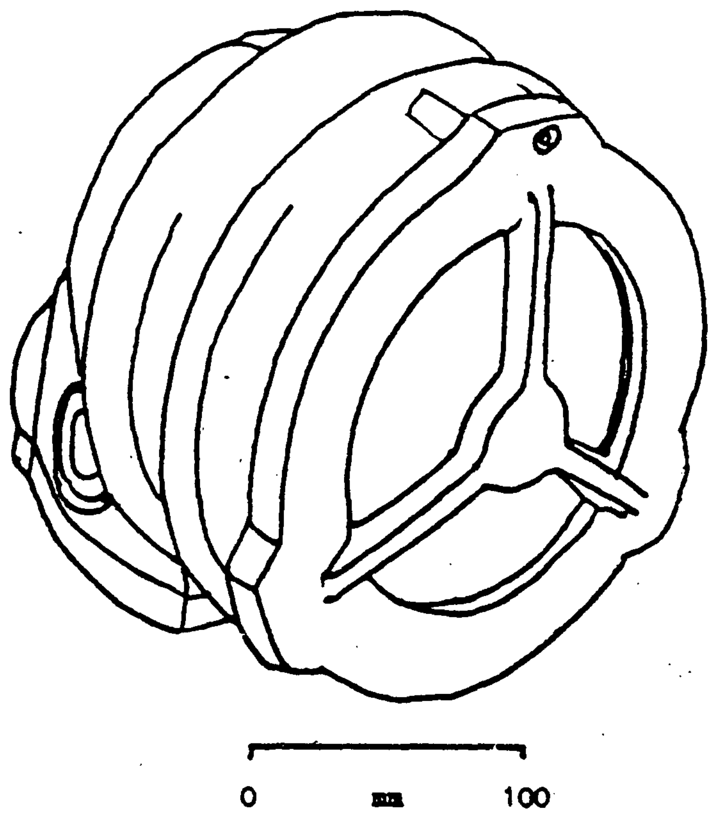
Headlight A



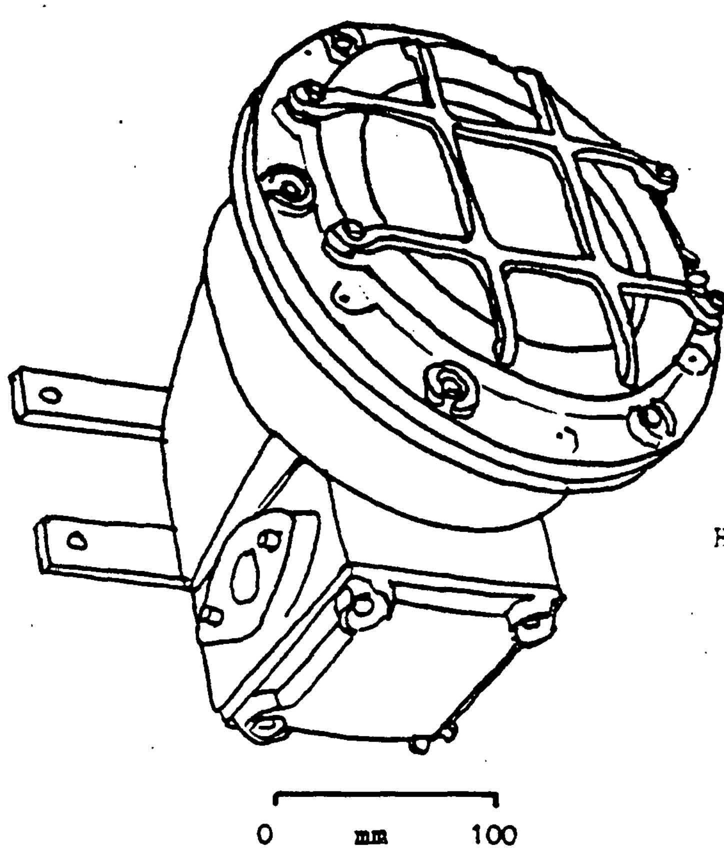
Headlight B

FIGURE 5 - Headlights A and B

FIGURE 5.

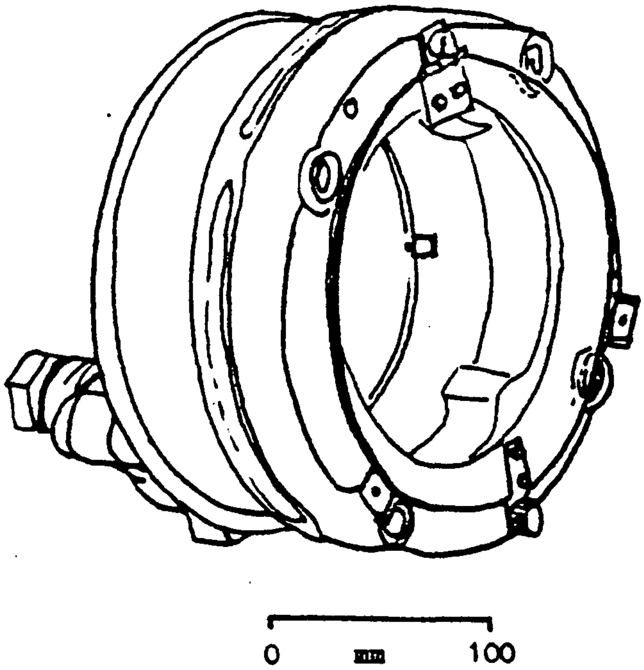


Headlight C

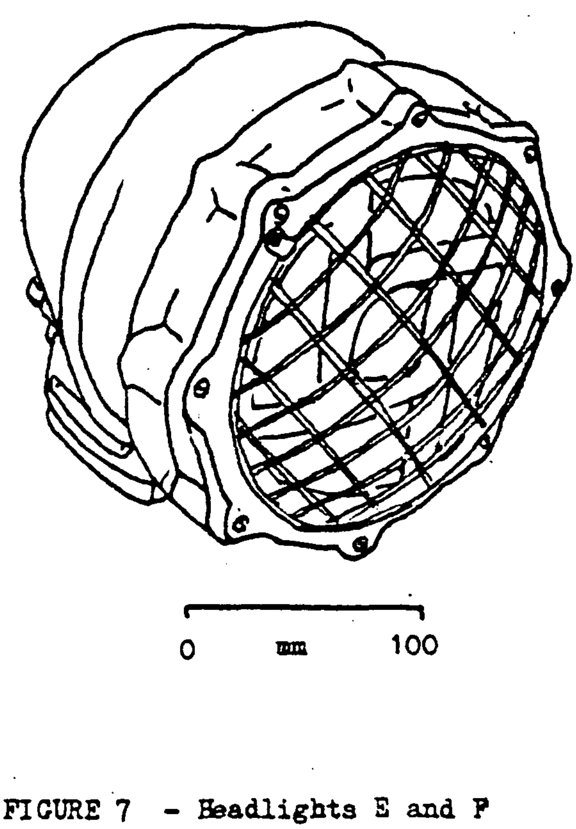


Headlight D

FIGURE 6 - Headlights C and D



Headlight F



Headlight E

FIGURE 7 - Headlights E and F

FIGURE 7.

reflectance values for rust and white paint illustrate.

TABLE 9

Light Reflecting Powers of Surface most frequently seen Underground

Reflecting Surface	Reflection Power
Coal Dust	4%
Rust	9%
Stone Dust	63%
Whitewash	72%
New White Paint	74%

3. VISUAL REQUIREMENTS

Optimum light levels for a given location depend upon the complexity of tasks which miners are required to carry out within that location. The visual requirements of different groups of tasks were therefore examined. The tasks were studied by identifying task areas which required visual attention and adequate visibility. The detailed procedure followed is given in Appendix 1. Briefly, these areas were identified by interviewing workers in a representative sample of jobs and by observing them during the course of their work. Having identified all such areas (termed visual attention areas - VAAs), the visual task analysis sheet, illustrated in Appendix 1, was used to identify potential problems for visibility within each VAA. Visual problems associated with complete jobs were then assessed by compiling summary sheets of potential problems, such as those for general activity illustrated in Tables 10 and 11.

Three categories of task were identified - General Activity, Close Work, and Tasks including Distance Work.

3.1 General Activity

General activity was classified as that activity associated with travel to or from the place of work or between different workplaces or as an integral part of a task such as accompanying mine cars along roadways. General activity occurred in all areas of collieries and with every type of lighting condition.

It was observed that during general activity specific visual detail was not normally required. All visual attention areas of this type were considered to be "secondary" targets, with visual attention areas from which miners required specific visual detail labelled as "primary" targets.

3.1.1 Visual Problems Resulting from the Absence of General Lighting

Visual problems were identified as those arising from lack of general lighting, and those produced by the general lighting when used. Table 10, summarizing the visual effects of absence of general lighting, shows that all sections of roadways were of visual interest when walking along them.

TABLE 10

Visual Attention Areas with Problems caused by the Absence of Mains Lighting - General Activity

Visual Limitations / Visual Attention Areas	Lines of Sight			Task Size/ Distance	Light Effects							Operator Position		Environmental Factors		Interaction Effects		
	Objects In Way	Interaction	Conflict		Distribution	Contrast	Glare	Shadow	Shadow Relief	Depth perception	Levels	Scope For Movement	Implications For Safety	Water Spray	Dust	Time	Transient Adaptation	Peripheral Awareness
					cap lamp / general	cap lamp / general	cap lamp / general	cap lamp / general	cap lamp / general	cap lamp / general	cap lamp / general							
Walking Floor		*			*	*			*	*								*
Walls		*			*	*			*	*								*
Roof		*			*	*			*	*								*

* - Potential Problem Source (see Appendix 1)

TABLE 10.

Failure to see an obstruction or projection could result in miners stumbling or hitting their heads. A survey of 101 miners at one colliery showed that 25% of those interviewed thought that stumbling was a problem due to the available lighting. Five percent thought that hitting their heads was more likely than stumbling. This was related to work area, with miners who worked in certain areas, e.g. gate roads and the coal face, regarding hitting their heads as the greater problem. Evidence for the extent of this problem can be obtained from Figure 8 which shows statistics on stumbling, falling and slipping accidents for 1974 - 1978 (Health and Safety Executive, 1978). The Figure shows fatalities and serious accidents for the period. The report stated that one in four accidents occurred when workmen were walking to or from their place of work, on roads which could be uneven or affected by water.

When walking along roadways it was noted that the cap lamp was usually directed at a point approximately 6 - 7 m ahead of the wearer giving a light level on the floor of between 4 and 5 lux. In spite of the fact that this level would be considered low if compared to recommended levels for general activity in other industries, Table 10 indicates that miners did not consider light levels, per se, a problem.

The majority of problems reported as potential causes of slipping and stumbling by miners questioned could be related to limitations in peripheral vision.

As the cap lamp illuminated only a limited area of the visual field, this resulted in an interaction between the areas of the roadway competing for direct attention, as indicated in the Table. This was particularly a problem in smaller roadways such as gate roads, and in areas where machinery or supplies could cause an obstruction because movement of the observer's head to point the cap lamp meant that there was less opportunity to see a particular hazard in any one area.

During surveys of the visual effects produced by cap lamp light, it was observed that reflected light from a miner's lamp could increase the peripheral awareness of other workers in the area. Initial tests in the field suggested that 5 lux of ambient light increased the peripheral vision

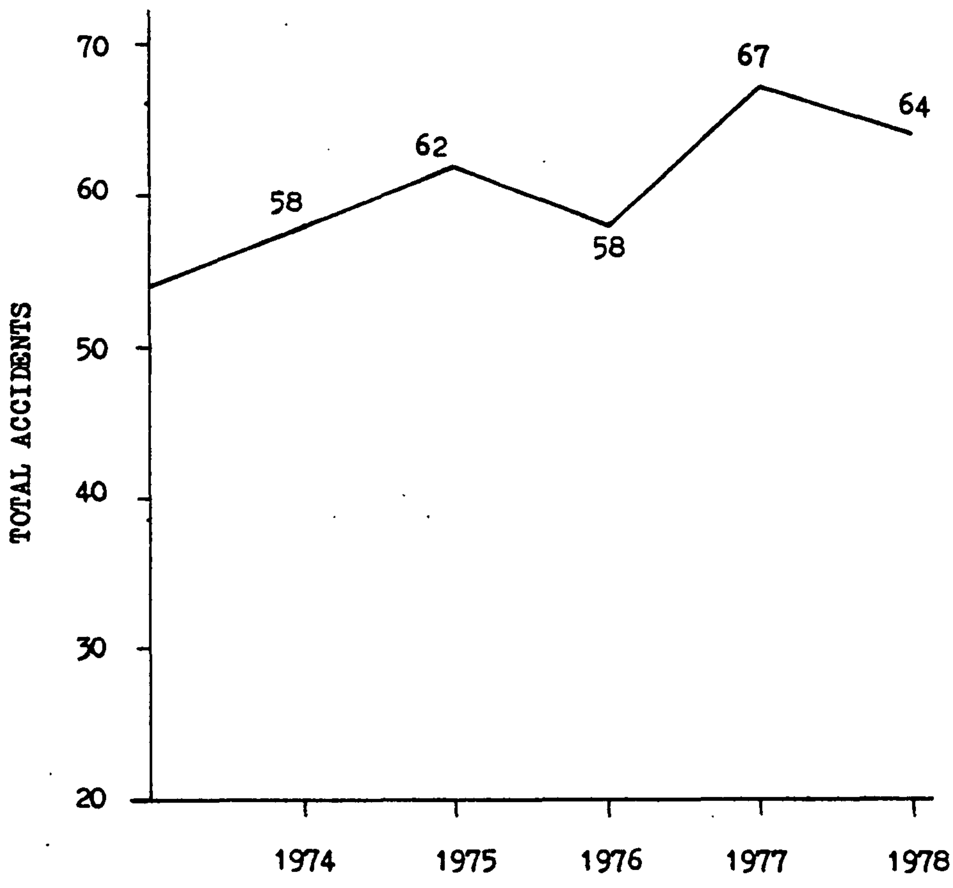


FIGURE 8 - Stumbling, Falling or Slipping Accidents Underground, 1974-78 (from Health & Safety Executive (1978))

of observers significantly although this depended on the contrast between visual targets and their backgrounds. Since the main requirement during general activity was for detection of secondary targets only, it was hypothesised that an ambient light level of 5 lux could improve the visual capacity of miners during this type of activity. A study was conducted therefore to test this hypothesis (Section 4.3).

Table 10 shows two other visual effects which were attributed to the location of the cap lamp, i.e. in line with the wearer's line of sight. There was a tendency for this to produce a visual effect of a flattening of the visual field. It was difficult, therefore, to judge the height of cables and other objects above roadway floors, or the extent to which objects protruded from walls. It is possible that this was connected with, or caused by, the other visual effect of cap lamps which was to minimise effective shadows, thereby removing an important source of cues in the absence of colour and light-reflection contrast.

To alleviate these visual effects, many miners carried their lamps in their hands with the cable hung over their shoulders. This enabled a miner to point his lamp independently of the position of his head. It also cast more shadow in the field of view because the beam originated from a different point to that of the wearer's line of sight.

Section 4.4 describes an experimental investigation of this observed depth perception phenomenon.

3.1.2 Visual Problems with General Lighting Table 11 summarizes the visual effects on general activity produced by general fixed mains lighting.

Less than 1% of miners interviewed considered that the light levels provided by fixed mains lighting were a visual problem, although where local lighting conditions were less good, this rose to 5%. A comparison of Tables 10 and 11 shows that with the addition of general lighting, the problems of peripheral vision and contrast vision were removed. However, mains lighting produced its own visual problems in certain areas. Table 11 shows that shadow and inadequate light distribution were a problem

TABLE 11

Visual Attention Areas with Problems caused by the Addition of Mains Lighting - General Activity

Visual Limitations / Visual Attention Areas	Lines of Sight: Objects In Way	Lines of Sight: Interaction	Lines of Sight: Conflict	Task Size/ Distance	Light Effects: Distribution (cap lamp)	Light Effects: Distribution (general)	Light Effects: Contrast (cap lamp)	Light Effects: Contrast (general)	Light Effects: Glare (cap lamp)	Light Effects: Glare (general)	Light Effects: Shadow (cap lamp)	Light Effects: Shadow (general)	Light Effects: Shadow Relief (cap lamp)	Light Effects: Shadow Relief (general)	Light Effects: Depth perception (cap lamp)	Light Effects: Depth perception (general)	Light Effects: Levels (cap lamp)	Light Effects: Levels (general)	Operator Position: Scope For Movement	Operator Position: Implications for Safety	Environmental Factors: Water Spray	Environmental Factors: Dust	Interaction Effects: Time	Interaction Effects: Transient Adaptation	Interaction Effects: Peripheral Awareness
Walking Floor																									
Walls					*	*						*													
Roof					*	*						*													

* - Potential Problem Source (see Appendix 1)

in some areas. The light distribution characteristics of tubular fluorescent luminaires placed across the roadway (Section 2.2.1.1) produced regular darkened areas on roadway walls. Luminaires positioned in line with the roadway also caused shadow at floor level when light distribution was obstructed by the mine cars. Both these problems were reduced by luminaires placed on alternate walls.

Mains lighting at transfer points often consisted of a single luminaire. This was sometimes inadequate to illuminate a confined area containing two roadways, one or more sets of steps, a transfer chute and a tannoy station. Walkways and ladders which were in shadow were a feature of these areas. Also, points where miners crossed under conveyor belts were not usually provided with special lighting and this produced uncertainty about headroom when crossing. Luminaires intended to provide light at steps to manriding belts were sometimes incorrectly positioned by being placed too far along the belt. This resulted in shadow on the steps.

The mains lighting designed specifically for face ends (600 mm, 20W) was the only mains lighting observed during the present study which caused miners to complain of discomfort glare. Comparison of the light levels and distribution of light from these and the intriniscally safe luminaires seen in similar locations showed that the latter luminaires were preferable on the basis of improved uniformity of light distribution and reduced luminaire surface brightness.

Both types of lighting used on the coal face were considered to be adequate for moving along the travelway.

3.1.3 Conclusions In all areas of general activity a uniform ambient light level removed at least five of the six problems produced by the use of the cap lamp as the sole source of light.

3.2 Close Work

The majority of visual attention areas identified were those required for close work. This included all manual tasks and the manual element in the control of machines. Of the 23 major areas of visual attention found to be required for face and heading operation, 16 were within arms reach of the operator at the time they were required to be seen. Although some tasks, for example the use of a spanner, required only one area of adequate visibility, most jobs were made up of a number of VAAs which all required adequate visibility individually and when interacting with each other. These may be located at various distances from each other or require a wide angle of view for all of them to be seen.

The transfer of supplies from the pit bottom to the face end, through areas of markedly differing light levels and distribution, provided the opportunity to carry out a detailed examination of the effect of such factors on various close work tasks associated with this procedure.

An additional factor was that two or more men usually worked together on supplies haulage, introducing the additional potential factor of glare from the cap lamps.

3.2.1 Visual Problems Caused by the Absence of General Lighting

Table 12 lists four areas of visual attention related to haulage of supplies. Wagons were of different types and could be either flat or have sides, as in the case of mine cars. Workers required to see the side of the wagon to lift supplies clear of it when loading and unloading. Supplies ranged from very small items such as bolts, to sections of archways, timbers, etc.. These were often stored by the roadside and workers required a clear view of the extremities of individual items for safe handling without other items slipping. Wagons were secured by pins in eye bolts (couplings) and adequate visibility of the eye bolt against its background was needed to insert the pin. There was a similar requirement in the use of lockers, which were tools used to secure halted wagons by inserting them into the spokes of the wagon wheels. Adequate visibility of the spaces between spokes was required for this purpose.

The Table shows that levels of light provided by the cap lamp were not considered to be a visual problem by miners. Levels were usually very

TABLE 12

Visual Problems Caused by Close Work during Haulage Supplies - General Lighting Absent

Visual Limitations / Visual Attention Areas	Lines of Sight			Task Size/ Distance	Light Effects							Operator Position		Environmental Factors		Interaction Effects		
	Objects In Way	Interaction	Conflict		Distribution (cap lamp / general)	Contrast (cap lamp / general)	Glare (cap lamp / general)	Shadow (cap lamp / general)	Shadow Relief (cap lamp / general)	Depth perception (cap lamp / general)	Levels (cap lamp / general)	Scope For Movement	Implications For Safety	Water Spray	Dust	Time	Transient Adaptation	Peripheral Awareness
Wagons		*			*													*
Materials					*		*											*
Lockers		*			*	*												*
Coupling		*			*	*												*

* - Potential Problem Source (see Appendix 1)

much higher than those which would have been provided by a mains lighting system. As can be seen from Table 3 (Section 2), illumination provided on a working surface by the cap lamp ranges from 8,600 lux at 0.25 metre to 800 lux at 1 metre.

A low level of contrast between a visual attention area and its background, in conjunction with low ambient light levels, was a visual problem in some circumstances, particularly when handling lockers and couplings.

As was the case with general activity, miners questioned reported a variety of visual problems which could be related to limitations imposed on peripheral vision by the limited distribution of light from the cap lamp beam. The problems reported were generally related to the confined working space which miners frequently worked in and to difficulties produced because of the size, weight and shape of materials being handled. An interaction of these factors could result in slipping and stumbling accidents.

Unlike general activity, problems related to the perception of depth were not considered to be a limitation to the loading and unloading of supplies although it remained a limitation to the general activities associated with the haulage of supplies such as accompanying mine cars in transit.

A visual problem resulting from the necessity for workers to face each other under some circumstances was glare from each others cap lamps.

3.2.2 <u>Visual Problems with General Lighting</u> Table 13 shows the visual effects created by mains lighting. A comparison of this Table with Table 12 shows that the principal improvement over the cap lamp was to increase peripheral vision which was no longer considered to be a problem with the addition of any of the lighting systems seen during the study. Nearly all VAAs were in shadow intermittently because of their positions relative to the light sources and mine cars or workers. This was particularly noticeable when supplies were being loaded/unloaded and workers themselves formed an obstruction between the lighting and the supplies.

TABLE 13

Visual Problems caused by Close Work during Haulage of Supplies - General Lighting Present

Visual Limitations / Visual Attention Areas	Lines of Sight			Task Size/ Distance	Light Effects														Operator Position		Environmental Factors		Interaction Effects		
	Objects In Way	Interaction	Conflict		Distribution		Contrast		Glare		Shadow		Shadow Relief		Depth perception		Levels		Scope For Movement	Implications for Safety	Water Spray	Dust	Time	Transient Adaptation	Peripheral Awareness
					cap lamp	general	cap lamp	general	cap lamp	general	cap lamp	general	cap lamp	general	cap lamp	general	cap lamp	general							
Wagons												*													
Materials					*	*			*	*		*													
Lockers					*	*						*													
Coupling					*	*						*													

* - Potential Problem Source (see Appendix 1)

3.2.3 Conclusions As with general activity, factors associated with depth perception and peripheral vision were regarded, in most jobs observed, as being potential problems when the cap lamp was the sole source of light.

The provision of mains lighting counteracted these effects but was shown to produce other visual problems. Several of the visual attention areas were to the side of mine cars and, depending on the location of luminaires, could be in shadow. As with general activity, the extent of this as a potential problem was reduced by the location of luminaires alternately on the roadway walls, or more specific task lighting and attention to other improvements such as whitewashing and stonedusting, thus increasing reflected light.

3.3 Close and Distance Work

For some underground work, the ability to see for a distance, in addition to close work, was necessary. This applied mainly to the use of machines, with the necessity to see to or beyond the point of application of the machine dependent on the task. Some machines, for example locomotives and heading machines, have been equipped with lighting systems, but as with other lighting underground, this has mainly been the result of technical developments rather than based upon an analysis of operator requirements. For example, the lamps fitted to heading machines are usually the same as those fitted to locomotives despite the different visual ranges involved in operating these machines. Heading machine drivers have a required viewing distance of 3 - 7 m, whereas the required viewing distance for most locomotive drivers is 60 m.

The operation of shearers was selected for detailed visual requirement evaluation on the basis of a preliminary assessment of machine operation which indicated that the working environment for these machines was likely to generate more visual requirement problems than other groups of machines. Attention was paid, however, to some aspects of locomotive and heading machine operation.

3.3.1 Visual Requirements for Face Cutting Machine Operators The study of the operation of face cutting machines showed that workspace restrictions were generally severe, with more areas requiring visual attention than for other activities so far studied. On one face, a direct comparison of operating with and without mains lighting was possible because a large section of the mains lighting fitted was not operational.

Observations were carried out at one colliery on a number of coalfaces all in the same seam. Each face had one twin-drum shearer (2 operators) and a single-ended shearer. A characteristic of the seam was a narrow band of dirt through the centre which was used as a cutting guide by all shearer operators.

At regular intervals an operator needed to observe the coal face, roof and floor in both directions from the machine, the orientation of the cutting drum with respect to the face, the machine controls and the travelway in the direction of travel. Generally, he would attempt to see as far as he could along the coalface in both directions from the cutting machine in order to observe his cutting line, and to look for snagging of the power cable and haulage chain and lifting of the armoured flexible conveyor (AFC).

3.3.1.1 Visual Problems Resulting from Lack of Mains Lighting

Table 14 summarises the visual problems identified from observing and interviewing operators on all shifts.

The Table illustrates that light levels provided from the cap lamp were considered a potential limitation in some circumstances, unlike the levels provided for general activity and close work. For example, light levels from the cap lamp, on the armoured flexible conveyor, fell to less than 1 lux at 10 m. Comparisons with other (surface) visual tasks are difficult because of the greatly differing visual environments. However, as a guide, the National Coal Board recommended light level for conveyors in coal preparation plants is 22 lux (NCB, 1969).

All of the visual attention areas which continued to the limits of the illumination provided by the cap lamp were primary, i.e. information was required from them. More light was required, therefore, than would be required for general activity.

The variation between the light levels in these more remote areas and the much higher light levels produced at close quarters was a potential

TABLE 14

Visual Attention Areas Required for Close and Distance Work during Operation of Face Shearer with Visual Problems caused by the Absence of Mains Lighting

Visual Limitations / Visual Attention Areas	Lines of Sight			Task Size/ Distance	Light Effects							Operator Position		Environmental Factors		Interaction Effects		
	Objects In Way	Interaction	Conflict		Distribution (cap lamp / general)	Contrast (cap lamp / general)	Glare (cap lamp / general)	Shadow (cap lamp / general)	Shadow Relief (cap lamp / general)	Depth perception (cap lamp / general)	Levels (cap lamp / general)	Scope For Movement	Implications For Safety	Water Spray	Dust	Time	Transient Adaptation	Peripheral Awareness
Shearer Drum		*							*	*				*	*			*
Shearer Controls																		*
Haulage Chain	*				*	*			*	*	*	*	*				*	*
AFC	*	*			*					*	*	*	*				*	*
Bretby Cable + Handler	*	*			*	*			*	*	*	*	*				*	*
Travel-way		*																*
Roof		*			*				*	*	*	*	*					*
Dirt Band		*			*				*	*	*			*	*			*
Coalface		*			*				*	*	*							*

* Potential Problem Source (see Appendix 1)

TABLE 14.

limitation when changing visual attention between such areas. The values from Table 3 illustrate that changing attention from close work at the shearer controls to look along the face could produce light level differences of up to 10,000:1. Stevens (op cit) estimated that the maximum useful instantaneous range of the eye was approximately 1,000:1 depending upon the luminance levels encompassed by the range. He stated also that when the general field luminance to which the eye must adapt is low, any area which requires visual attention whose surface is less bright, may appear black by comparison. Since face operators' cap lamps produced surface luminances of 10^{-2} to 10^{2} cd m^{-2}, it was concluded that VAAs at the lower end of the range could appear black, and therefore lack the necessary detail for adequate visibility. Poor visibility of these visual attention areas was also a function of contrast. The low levels of light reduced the effective contrast between these areas and their background, thus removing an effective aid to visibility in areas of low reflectance contrast and low colour contrast.

The visual problems created by the cap lamp, notably those of reduced peripheral vision and inaccurate appreciation of depth were reported here as in the other areas of colliery activity. Factors connected with reduced peripheral vision were considered to be a general limitation. The effect of this was emphasised by the distance and visual angle of separation of some visual attention areas along the coal face which were in complete darkness when attending to areas close to the machine. The overall effect was to reduce appreciation of the exact layout of the surrounding workplace.

The combined effects of wearing the cap lamp on the head, i.e. lack of contrast caused by lack of visible shadows, and an incorrect perception of depth, was a particular problem in areas with no regular boundaries and of the same colour and texture as the surrounding areas. For example, cavities in the coalface or roof could be very difficult to see, potentially an important factor on faces with unstable face and roof conditions.

3.3.1.2 Visual Improvements Resulting from the Addition of General Lighting

Table 15 summarises the visual improvements produced by the combination of fixed mains lighting and personal lamps on the coal face. The Table indicates that problems relating to peripheral awareness were considered to have been removed. Mains lighting solved the problem of perception

TABLE 15

Visual Attention Areas Required for Close and Distance Work during Operation of Face Shearer with Visual Problems caused by the Addition of Mains Lighting

Visual Limitations / Visual Attention Areas	Lines of Sight			Task Size/ Distance	Light Effects														Operator Position		Environmental Factors		Interaction Effects		
	Objects In Way	Interaction	Conflict		Distribution		Contrast		Glare		Shadow		Shadow Relief		Depth perception		Levels		Scope For Movement	Implications For Safety	Water Spray	Dust	Time	Transient Adaptation	Peripheral Awareness
					cap lamp	general	cap lamp	general	cap lamp	general	cap lamp	general	cap lamp	general	cap lamp	general	cap lamp	general							
Shearer Drum		*										*									*	*			
Shearer Controls												*													
Haulage Chain	*				*	*	*	*				*	*	*	*	*	*	*	*	*				*	
AFC	*	*			*	*						*			*	*	*	*	*	*				*	
Bretby Cable + Handler	*	*			*	*	*	*				*	*	*	*	*	*	*	*	*				*	
Travel-way		*																							
Roof		*			*	*	*	*				*	*	*	*	*	*	*	*	*					
Dirt Band		*			*	*						*					*	*			*	*			
Coalface		*			*	*						*					*	*							

*Potential Problem Source (see Appendix 1)

TABLE 15.

of depth and contrast vision resulting from the position of the cap lamp, where light distribution was not obstructed by equipment. For example, even though the light levels reaching the actual coal face were less than one lux, this was still adequate to provide some improvement in visibility of the face profile. Many of the remaining visual limitations identified were a result of poor light distribution. Thus the roof and floor (AFC, haulage chain and Bretby Cable Handler) were still in shadow, an effect possibly accentuated by higher light levels at other areas. Even where unobstructed by physical objects, the light distribution forward to the face was low in relation to the total light output. Alternative luminaire designs/locations may improve distribution of light. Section 4.2 describes an experiment carried out in an attempt to identify the optimum location for face lighting luminaires.

3.3.1.3 Visual Problems Resulting from Obstructed Lines of Sight for Shearer Operators At some workplaces underground, obstructed lines of sight presented more immediate limitations to visibility than did inadequacies of lighting. They were a particular problem in work areas containing a combination of limited work space, and large machine components whose size sometimes prevented workers from seeing important visual attention areas.

The visual attention areas required for the job of operating the shearer were obtained from observations by investigators and interviews with operators. The results were listed under Section 3.3.1.1. The most important of these, from the point of view of control, were the floor and roof, a clear view of which was important in maintaining a satisfactory cutting line. Mason et al (1977) showed that a clear view of these could not be obtained from the required operating position, i.e. in the travelway stationed at the machine controls. Various strategies were observed as operators attempted to improve visibility of these areas, including lagging behind the machine as it moved along the face. This introduces a time lapse between observing any deviation from the required line and correcting it. Following the recommendations of Mason et al (op cit) some new machines have been produced with some controls duplicated at both ends of the machine, which appears to have reduced this effect on task performance. Long-term approaches to this problem by other groups include the use of remote control and automatic height controls.

3.3.2 Visual Requirements for Haulage Locomotive Drivers Two general groups of visual attention areas related to driving locomotives were identified. These were close work (control operation and gauge inspection) and distance work (roadway observation). A variety of controls and gauges, requiring operation and/or monitoring, were situated within the cab. Externally, the driver required an adequate view of a number of areas requiring visual attention. Primary visual attention areas included points, traffic information and signals. Secondary visual attention areas included any potential obstructions on the track.

3.3.2.1 Visual Problems Resulting from Lack of Cab Illumination
Locomotive cabs are not generally provided with illumination and consequently drivers have to use their cap lamps to illuminate controls and displays. However, the relatively high incident light levels, produced on display surfaces by the cap lamp interfered with the driver's visual adaptation to the comparatively low light levels along the roadway. In addition, approximately 15% of locomotives in use in the National Coal Board (particularly newer models) are fitted with windscreens and, in those observed, the cap lamp beam was reflected in the glass, producing discomfort glare and disability glare. As a consequence, drivers normally kept their cap lamp turned off and used it intermittently to check internal displays as these were not internally illuminated. This reduced the glare problems but aggravated adaptation problems. Some drivers also reported disability glare from reflections of the cap lamp beam in the glass covers of gauges. Kingsley et al (1980) discussed various means of providing illuminated displays which do not cause problems including the use of LEDs and fibre optics. Initial trials of fibre optic systems by the National Coal Board, Headquarters Transport Branch have shown that this method is highly effective and holds considerable promise. Lack of illumination on controls was identified as a potential source of confusion to drivers when using infrequently-used controls whilst under pressure. This also applied to drivers who drove more than one type of locomotive, and to new drivers. The use of general cab illumination could also cause adaptation problems.

3.3.2.2 The Effectiveness of Locomotive Headlamps The British Health and Safety Executive require headlamps to be fitted to locomotives and to have "a range of at least 60 metres" (Health and Safety Executive, op cit). Table 2 (Section 2.1.2) showed that the locomotive headlamps available for use underground produced light levels, at a distance of

60 metres, of 0.17 to 43.47 lux, thus complying with the regulation. However, no indication was given within the regulation of the required effectiveness of the illumination at that distance.

A field survey was carried out amongst locomotive drivers to determine their subjective opinions of the general illumination provided by the lamps fitted to their locomotives. Sixty-nine percent of drivers interviewed described the headlamps as very poor and over twenty percent described them as poor. Tests were carried out to examine more specifically the illumination provided by the headlamps at 60 metres. The light from the headlamps fitted to a number of different locomotives covering 16 different combinations of lamp design and bulb type was examined using a series of 300 mm x 300 mm square 'targets' of different reflectances. It was found that the visibility provided by the illumination levels from the lamps was generally poor. For example, with 9 of the 16 headlamps tested, it was not possible to see a target made from the orange fabric used for the protective clothing generally issued to the workforce (30% reflectance).

Because of the variety of factors which can influence the effectiveness of a headlamp, a more detailed study of the visual discrimination and detection permitted by the varying light levels from these lamps was incorporated into the study of headlamp lighting characteristics referred to earlier, and is reported in Section 4.1.

3.3.2.3 <u>Improvements to Visibility Provided by Mains Lighting</u>

Where roadway walls were regularly treated with whitewash or other high-reflectance material, mains lighting reflected into the cab provided adequate control illumination thus alleviating this problem. However, as mains lighting on locomotive routes was generally limited to major roadways, junctions and other specific areas, this was not a substitute for adequate internal cab illumination.

External visibility was regarded by all drivers as being improved by mains lighting. This applied particularly to roadway walls which were poorly illuminated by the comparatively narrow headlamp beam. Mains lighting also improved the detectability of obstructions lying on the rails. This was because light was reflected off the smooth upper surface of the rails giving them a very bright appearance (70 cd m^{-2}) relative to the floor (less than 1 cd m^{-2}). Any obstruction, therefore, appeared as a dark break in the continuity of the lines. This phenomenon also facilitated the observation of the status of points at junctions. It is unlikely that lighting from headlamps would provide this type of visual aid because of its location relative to the driver.

3.3.2.4 Lines of Sight for Locomotive Drivers All locomotives had design aspects which caused problems for visibility because of physical obstructions to lines of sight, particularly during complex manoeuvres such as shunting. Table 16 shows how 17 drivers rated visibility from the two most commonly used locomotives when pushing or pulling mine cars forwards.

TABLE 16

Drivers' Visibility Ratings for Shunting Manoeuvres

		Very Poor	Poor	Ade-quate	Good	Very Good
Forwards	Pulling	0	6	2	11	1
	Pushing	6	6	3	5	0

It was found that during any manoeuvre in which the locomotive body or mine cars were in front of the driver, visibility was restricted. This was because of the relatively low-seated height of the driver or the difficulty in leaning out of the cab to see down the side of the haul. This is reflected in the Table where 12 of the 17 drivers rated visibility as poor or very poor when pushing mine cars forwards. Only when pulling mine cars forwards did 12 of the drivers regard visibility as good or very good.

3.3.3 Visual Requirements for Face End Machine Operators Face end machines could be classified into groups - those relatively stationary, e.g. roadheaders and gathering arm loaders, and those which moved more frequently within the heading, e.g. bucket loaders. Two main visual requirements were identified, the immediate working site, e.g. the drilling point, bucket, or cutting head (relevant to both groups); and the surrounding area into which the machine might be moved, clearly of more importance for the more mobile machines. Because of the development nature of the working areas, mains lighting is rarely provided and was never seen during the course of the study. Lighting is provided, therefore, by the cap lamp and, in some cases (Section 2.2.2.1), machine-mounted lamps.

3.3.3.1 Immediate Working Area Machine-mounted lamps, where observed, were rarely effective in adequately illuminating the working area. This was partly a function of light levels/distribution and partly due to lamp location.

Machines were observed fitted with lamps providing a narrow beam of light which was unsuitable as it did not distribute light over an adequate working area, particularly where boom-mounted cutting heads were used. Because of the nature of the work, light levels were reduced because of dirt on the lamp glass and difficulties in cleaning the lamps (Section 2.3.4), and the requirement for special tools for bulb replacement frequently resulted in failed bulbs not being replaced.

Headlamp location also contributed to the inadequacy of the lighting. They were frequently mounted on the main body of the machine and obscured by moving parts. A general illustration of this is shown in Figure 9. The lamps are fitted to the machine chassis, and their light may be obscured by the bucket whenever it is raised or lowered. Some lights were observed attached to the base of a drilling arm but, as the drill carriage could be moved independently of the arm, the light beam was only directed towards the drill bit when the drill and arm were in line, at which point the arm cast a shadow obscuring the bit. The headlamps seen were too large to be easily mounted on the drill carriage.

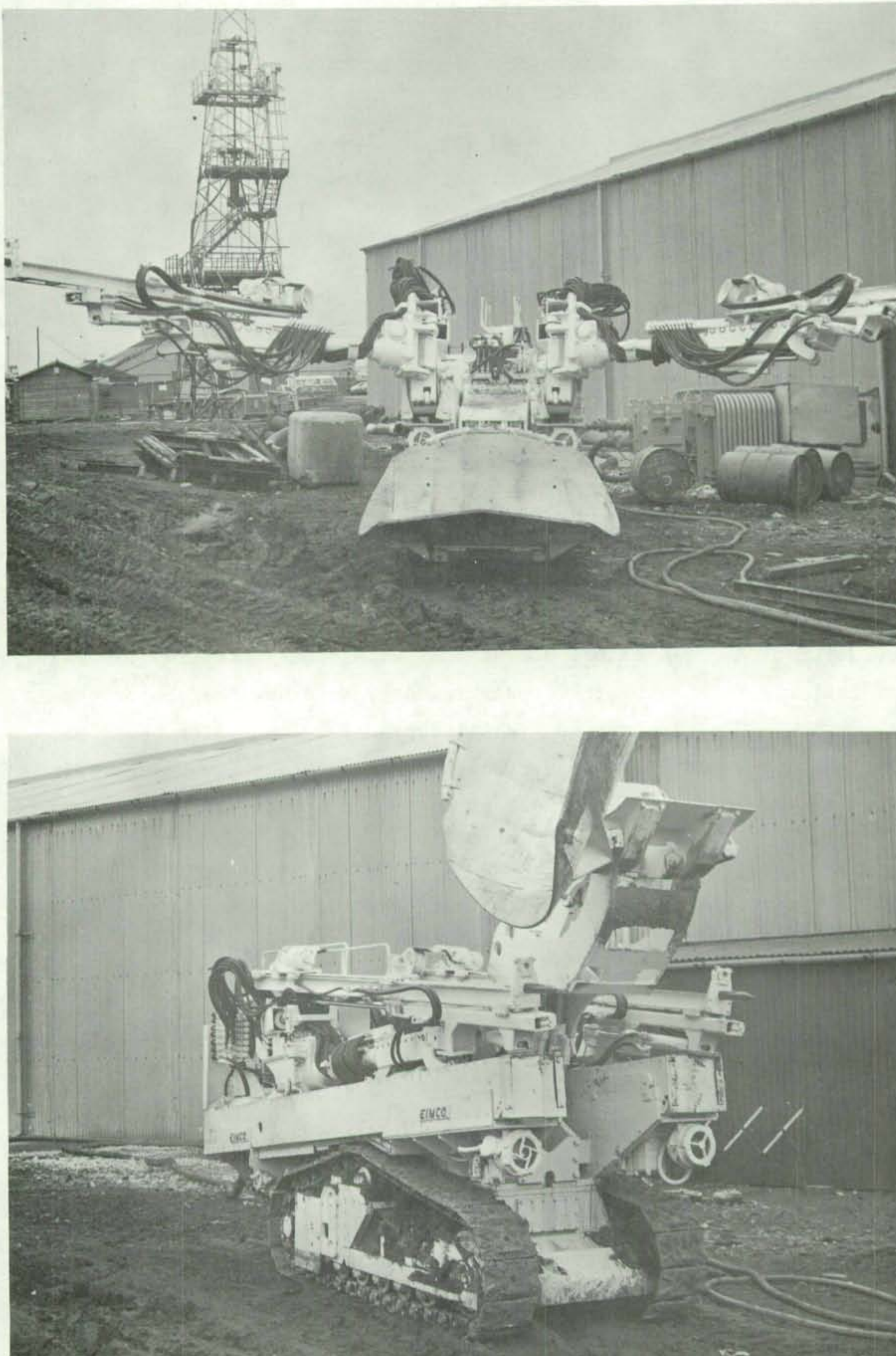


FIGURE 9 - A General Illustration of the Misplacing of Lamps on Heading Machines

Headlamps could also be a source of glare either for the machine operator, when light was reflected back from booms or buckets, etc. or for other workers carrying out activities in front of the heading machine. For example, when a bucket loader was feeding a mechanical packer the machine headlights could cause disabling glare for the packer operator.

Because of the observed limitations of machine lighting, operators generally regarded the cap lamp as a preferable source of illumination, sometimes to the extent of obscuring machine lights where their operation was automatic. Levels and direction of cap lamp lighting were adequate although, as with workers in previous areas, lack of shadow contrast contributed to depth perception difficulties on occasions.

3.3.3.2 Lighting for Moving within Heading Some machines, particularly bucket loaders involved a considerable degree of manoeuvring within the heading. Machine-mounted lighting for this was minimal with only 20% of such machines observed with such attachments. Observation of the operation of these machines showed that all-round visibility was required, particularly when reversing or working near to stage loaders or other equipment. The cap lamp as a sole source of illumination could not provide this because of the difficulty a seated driver would have in pointing the lamp in the correct direction on some occasions.

3.3.3.3 Lines of Sight from Face End Machines With some face end machines studies indicated severe problems with obstructions to lines of sight (Mason et al, 1980). This problem affected all areas requiring visual attention.

Visual obstruction of either the immediate working area or the area for movement was particularly a problem for the small miner (5th percentile). This was observed with most of the more common groups of machines. For example, with some bucket loaders, the bucket obscured the dirt pile when lowered, hindering efficient cleaning of the rip. When raised, the same bucket completely obscured the forward view, making loading out onto a conveyor or mechanised packer difficult. On a machine fitted with twin drilling rigs, the rigs obscured the roadway profile when drilling at the edges, masking over a metre in from each side of the roadway and could create problems in maintaining an even profile. Similarly, on a boom miner, a small miner sitting in the normal operating position would be unable to see the bottom two metres of the roadway profile. A general illustration of line of sight problems is shown in Figure 10. The Figure shows the non-visible areas of a development heading for a 5th percentile driver seated on a heading machine.

Similar problems were encountered with rearward vision for manoeuvring, with bulkheads and other machine parts obscuring the operator's view of the lower areas of the roadway, sometimes for a considerable distance.

3.3.4 Conclusions - Visual Requirements for Close and Distance Work

The problems of peripheral vision and depth perception produced by the cap lamp were again in evidence for the distance components of close and distance work. This was particularly true on the coal face where space limitations were most acute but, paradoxically, the distances involved in viewing the face could be large. Alternating between close and distance aspects could produce adaptation problems because of large differences in illumination levels. All these problems were reduced by providing mains lighting.

Mains lighting, where provided, was more suitable for general activity than for visibility of specific tasks. Consideration should be given to the provision of such lighting, for example above stores of supplies at roadway sides and areas of the coal face in front of the powered supports. The addition of general mains lighting would have aided locomotive drivers in detecting hazards on rails and in visibility of cab controls and displays.

Machine lighting was generally inadequate with nearly 90% of locomotive drivers regarding the illumination provided as 'poor' or 'very poor'. On heading machines, poor location of lamp units was a prime cause of this inadequacy. Consideration should be given to the provision of "flood" type lamps which could be varied to suit the particular conditions.

One major cause of dissatisfaction with machine-mounted lighting was the difficulty in cleaning and maintaining the units. Attention should be paid to designing such lamps to simplify these tasks.

Finally, detailed observation and task analysis showed that, where large machinery was involved as part of the task, parts of the machine could

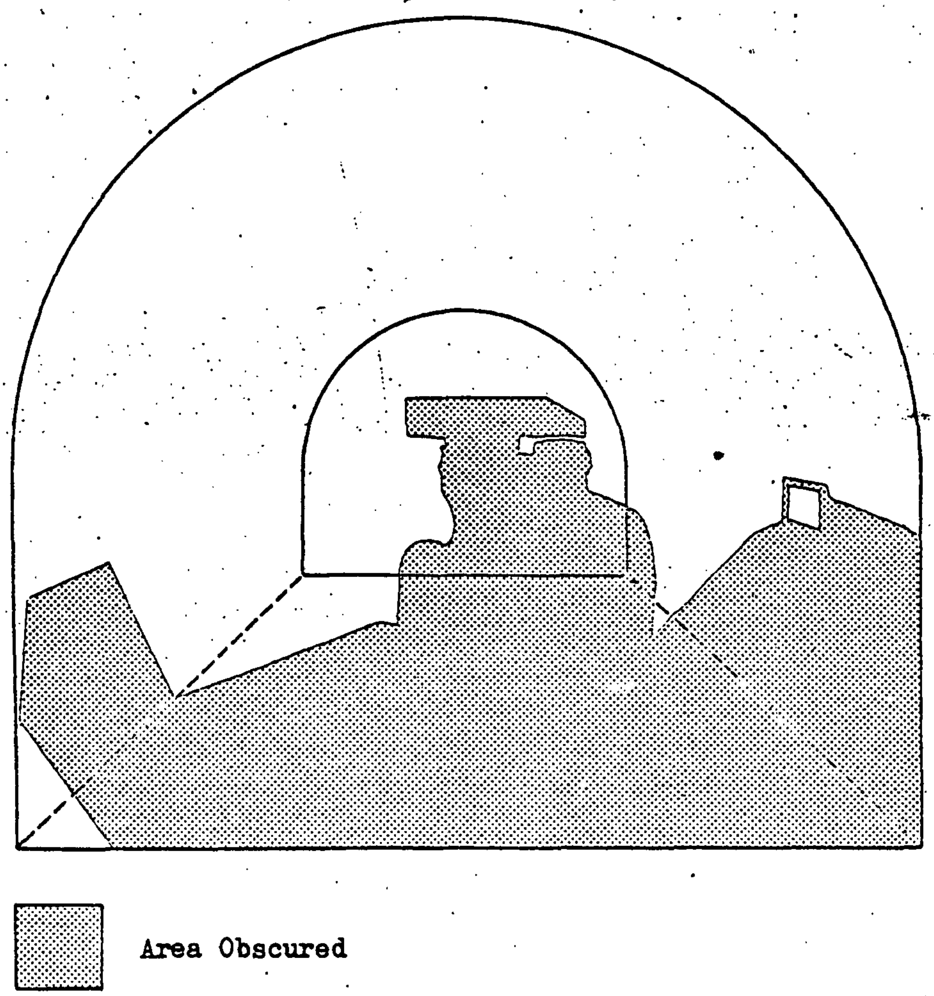


FIGURE 10 - A General Illustration of the Areas of a Development Heading obscured to the Driver of a Heading Machine

FIGURE 10.

obscure areas necessary for good task visibility. Kingsley et al (op cit) and Mason et al (op cit) have discussed these lines of sight problems and some potential solutions in detail.

4. STUDIES OF SOME PROBLEMS IDENTIFIED FROM THE EXAMINATION OF LIGHT LEVELS AND REQUIREMENTS

4.1 Variations in the Light Levels provided by Locomotive Headlamps, and the Effects of these Levels on Visual Performance

4.1.1 Light Levels and Distribution

4.1.1.1 Introduction Section 2 identified the need to examine the lighting characteristics of machine headlamps, including the effects of variations in location of the lamp units, on the distribution of light from them. Values were given for the decrease in light levels with horizontal distance from the lamp, to a distance of 60 metres, the distance specified by the Health and Safety Executive (op cit). In order to examine the patterns of distribution of light from the different units they were mounted on an adjustable height test rig in a straight tunnel. The distribution of light was measured across the width of the tunnel (3.6 metres) and to a height of 2.7 metres, at a distance of 60 metres from the light source. Figure 11 shows the measuring points used. Readings were taken for all six types of lamp certified for use underground. Three different conditions were adopted. The lamps were tested at mounting heights of 0.4 and 1.7 metres from the tunnel floor to examine the variation in light distribution with lamp location on locomotives. In addition, in order to examine the effectiveness of the spread of the beams, the lamps were tested at an angle of 10° to the line of the tunnel, simulating the distribution of light as a locomotive came round a bend into a straight section of roadway.

4.1.1.2 Results Table 17 shows the light levels obtained at the fourteen measuring points for each lamp for the three conditions.

4.1.1.3 Discussion The light levels obtained from the lamps were, with one exception, generally low, with over 80% of the measures taken being under 2 lux. The main exception, lamp F, was a new design of lamp which was not yet in use underground. Light distribution was relatively even. When mounted in the high position, most lamps provided lower light levels towards the floor except for lamp A which cast more light onto the floor than at higher levels. For some lamps, this pattern of distribution was altered when the lamps were located in the lower position, some with comparatively more of the light being directed towards the floor, others with a more even distribution of light. This was probably a function

FIGURE 11.

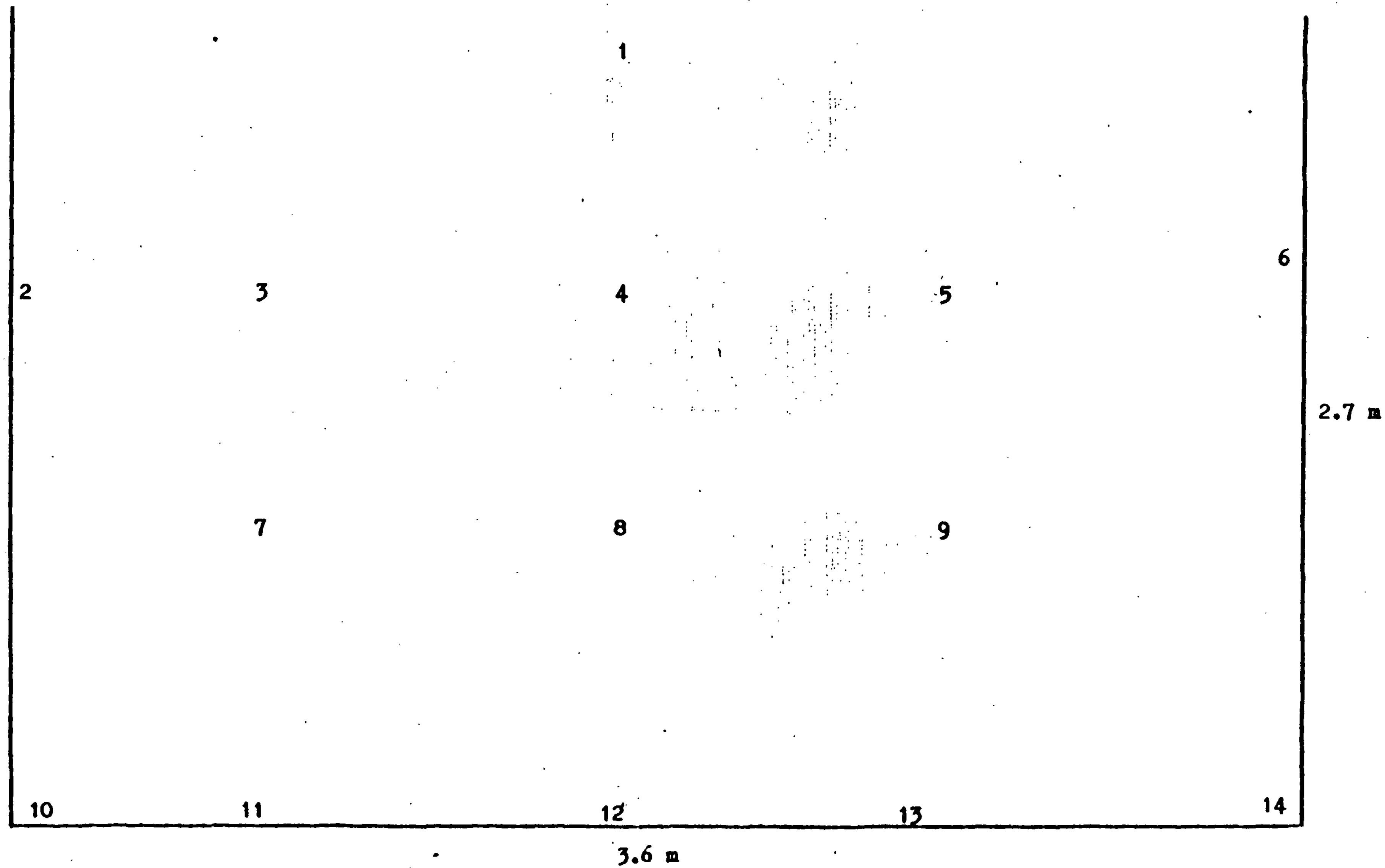


FIGURE 11 - Points at which Incident Light Levels were Recorded Related to a Roadway Profile

TABLE 17

Incident Light Levels (lux) at 60 metres for Three Different Headlamp Orientations

Lamp	Location	Recording Position													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
A	High	1.28	1.42	1.28	1.25	1.25	1.18	1.49	1.42	1.25	1.53	1.60	1.67	1.67	1.67
	Low	0.34	0.20	0.29	0.24	0.24	0.22	0.24	0.27	0.18	0.13	0.13	0.17	0.17	0.24
	Offset	0.23	0.31	0.27	0.17	0.15	0.10	0.56	0.10	0.08	0.21	0.18	0.06	0.06	0.06
B	High	0.76	0.60	0.62	0.73	0.73	0.73	0.56	0.58	0.63	0.51	0.50	0.50	0.57	0.58
	Low	0.29	0.20	0.31	0.29	0.30	0.30	0.24	0.31	0.29	0.18	0.22	0.19	0.20	0.23
	Offset	0.02	0.00	0.00	0.03	0.01	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C	High	0.16	0.06	0.10	0.13	0.15	0.16	0.11	0.11	0.10	0.10	0.10	0.10	0.10	0.11
	Low	0.20	0.20	0.20	0.23	0.20	0.25	0.23	0.20	0.27	0.20	0.17	0.20	0.17	0.18
	Offset	0.44	0.22	0.27	0.29	0.43	0.43	0.25	0.25	0.31	0.18	0.20	0.23	0.33	0.31
D	High	0.32	0.24	0.24	0.17	0.24	0.17	0.20	0.17	0.23	0.17	0.13	0.19	0.24	0.20
	Low	0.76	0.50	0.52	0.66	0.67	0.80	0.43	0.41	0.45	0.32	0.35	0.27	0.31	0.32
	Offset	0.10	0.31	0.20	0.11	0.06	0.04	0.18	0.08	0.04	0.15	0.13	0.10	0.03	0.00
E	High	6.46	5.05	6.30	6.61	5.89	5.54	4.28	4.21	3.72	1.88	1.77	1.77	1.74	1.34
	Low	2.75	1.35	2.30	5.50	1.32	2.50	5.15	6.41	5.85	3.97	5.75	2.33	5.80	3.27
	Offset	0.04	0.06	0.06	0.03	0.08	0.03	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.00
F	High	35.19	28.64	39.33	43.47	37.26	30.02	41.4	40.02	33.81	31.74	33.12	32.43	26.22	18.63
	Low	24.50	34.85	37.95	34.85	26.91	26.57	40.02	38.64	28.29	40.37	39.33	31.74	24.15	15.18
	Offset	0.10	0.25	0.06	0.10	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.10	0.00

of lamp design, particularly the protective grill (see Figures 5 - 7, Section 2.2.2.1).

The offset condition showed that the light beams from the lamps were generally too narrow, the most marked being the new lamp (F). The best levels were provided by lamp (C) (which was one of the worst lamps in the straight conditions). The maximum light level recorded from any lamp in the offset condition was 0.56 lux.

4.1.1.4 <u>Conclusions</u> All headlamps satisfied the Health and Safety Executive (HSE) requirement to have a range of at least 60 metres. However, the light levels provided at that distance were, with one exception, very low. The pattern of light distribution varied slightly with the lamp mounting height but also varied between lamps so that it was not possible to recommend a single mounting height for all units. The light levels provided in the offset condition were extremely low due to the narrow beam of light produced by the lamp units. This resulted in parts of the roadway area being unlit.

4.1.2 <u>Limitations to Visual Performance Produced by the Light Levels</u>
In order to determine the significance of the low light levels provided by five of the six headlamps examined, two tests of visual performance were carried out. Initial tests used Landolt 'C's to examine the visual performance of subjects who had 6/6 vision (the ability to discriminate 1 minute of arc) under normal lighting conditions. Seven light levels were used within the range of illumination provided by the five lamps in general use underground. These levels were - 6.55, 4.00, 2.92, 0.27, 0.17 and 0.1 lux. These tests were followed by further tests using as performance criterion the detection of objects which could be found in locomotive roadways.

4.1.2.1 <u>Visual Acuity: Landolt 'C' Tests</u> Landolt 'C' displays were presented to four subjects. The targets subtended 2.5, 2.0, 1.5, 1.0 and 0.5 minutes of arc. Each target was presented three times at each of the light levels listed above.

The general result, as shown in Table 18, was a reduction in visual acuity of subjects at low light levels with no more than 66% of correct responses to the 6/6 vision criterion of 1 minute of arc.

TABLE 18

Percentage of Correct Responses from Visual
Acuity Tests at Low Light Levels

Light Level (lux)	Size of Target (Minutes of Arc)				
	2.5	2.0	1.5	1.0	0.5
6.55	100	100	91	58	8
4.00	100	100	100	66	0
2.92	100	100	91	58	8
0.27	100	66	66	0	0
0.2	83	91	41	17	8
0.17	91	83	50	8	0
0.1	75	50	8	0	0

The Table shows also that very few correct responses occurred for the target requiring 6/3 vision (0.5 minutes of arc). The targets were constructed to achieve maximum contrast with their background and would be more discernable than the majority of mining objects found in locomotive roadways.

4.1.2.2 Visual Acuity - Mining Objects A second series of targets were assembled using typical objects that could be found in a colliery roadway. The objects included the 300 mm square of orange boiler suit material used during the preliminary headlamp tests (Section 3.3.2.2).

Four subjects viewed the objects from a distance of 60 metres using the same light levels as in the previous test. For each object, subjects were asked to state whether or not they could detect any object lying in the centre of the roadway. Table 19 lists the objects used and the number of subjects who could detect their presence under the different light levels.

The results indicate that the bright orange square was easily visible under all conditions. Similarly, the large wooden chock block was visible at all except the lowest light levels. However, the metallic objects were less readily detected, partly due to their lower reflectance (20% or less depending on the state of the surface) and partly due to their lower profile against the tunnel floor.

TABLE 19

Number of Subjects Detecting Objects in Roadway under Differing Lighting Conditions

Object and Size (mm)	Light Levels (lux)						
	6.55	4.00	2.92	0.27	0.2	0.17	0.1
Orange Square 300 x 300	4	4	4	4	4	4	4
Wooden Chock Block 125 x 125 x 610	4	4	4	3	4	3	2
Steel Lagging Board 40 x 380 x 1220	2	2	1	1	1	1	0
Shovel 60 x 320 x 1340	3	3	2	0	0	0	0
Arch Locking Strut 35 x 35 x 1230	2	4	2	0	0	0	0
Metal Connecting Plate 35 x 100 x 460	0	0	0	0	0	0	0

4.1.3 <u>Conclusions</u> Although all headlamps tested complied with the HSE requirement of a range of at least 60 m, the light levels provided at that distance were generally very low and resulted in significant reduction in visual performance of subjects who had 6/6 vision under normal lighting conditions. The tests with mining objects indicated that many items which could be found in mining roadways would not be detected at the lowest levels used and that minimum levels of 3 - 7 lux were necessary.

4.2 The Effect of Varying Luminaire Location on Powered Supports on the Distribution of Light

4.2.1 Introduction In National Coal Board Areas which favour face lighting, there are a variety of opinions on what is to be illuminated and, consequently, where to place luminaires on face supports. The majority opinion is that face lighting is primarily to illuminate the travelway. It was observed that placing luminaires in the travelway excluded light from reaching some parts of the floor and face because the design of face supports impairs the distribution of light. As a result, it was decided that a study should be carried out of some aspects of face lighting. More specifically, the study would be designed to examine the effects of varying the type and height of powered support and the location of the light source on the distribution of light.

4.2.2 Procedure Scale models of powered supports, an armoured flexible conveyor (including a cable handling device) and a single drum shearer were used to construct a model of a section of a coal face. Models of the most common powered supports for each of three ranges of extraction height were used (up to 105 cm, 105 - 150 cm, and over 150 cm).

Small lamp bulbs were located in three alternative luminaire locations based on positions seen during surveys. The positions used were central above the travelway, the side of a front leg and suspended between the rear legs. The different intensity shadows cast by the models were drawn at the planes representing the floor and coal face. A photometer was used to measure the luminance of the different areas of shadow. Each of the powered support types were studied using the three alternative luminaire locations either on each support or on alternate supports - a total of 18 different assemblies. The luminance values obtained were converted to a proportion of the maximum luminance obtained for a particular support/luminaire combination (luminance ratio) to allow assessment of the lighting differences between such combinations independently of actual luminance values.

The models were also inspected and the extent of illumination assessed subjectively for each of the main visual attention areas (VAAs) identified from previous visual requirements surveys. A criterion for acceptable illumination was adopted for this subjective assessment (of VAAs) such that 50% or more of the VAA was not in dark shadow.

4.2.3 Results Figure 12 shows an example of the changes in distribution

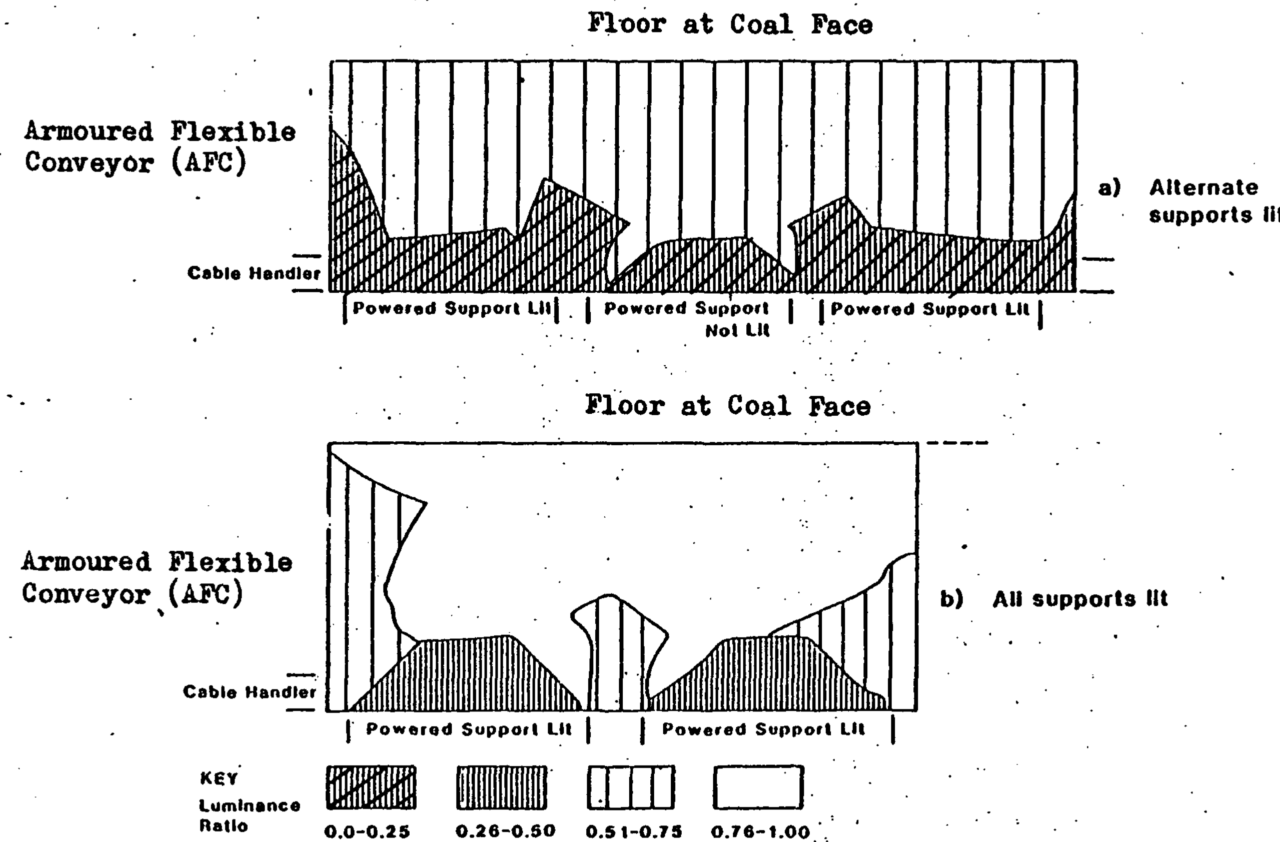


FIGURE 12 - Changes in Distribution of Light onto Floor of Coal Face, with Changes in Lighting (Plan View)

FIGURE 12.

of light when either alternate or all supports were fitted with luminaires. Table 20 provides a summary of the VAA illumination assessments for all supports/luminaire location combinations.

4.2.4 Discussion The benefit derived from attaching luminaires to every support was generally limited to increasing the light levels on areas already illuminated, with few extra areas becoming illuminated. Figure 12 shows the improvement in distribution of light in changing from alternate supports illuminated to all supports illuminated (Support C, side of front legs). The principal area where light distribution was improved was the cable handler, immediately in front of the supports. This was supported by the assessment of the visual attention areas (Table 20) where, with all supports illuminated, the light levels on the cable handler satisfied the illumination criterion of a minimum of 50% of its length being illuminated. Dark shadows were also removed from the picks on the shearer drum. These were the only two visual attention areas to have dark shadows removed when luminaires were fitted to every support.

The optimum luminaire location varied between supports. For support A, all locations cast heavy shadows onto the AFC and cable handler. However, with all supports illuminated, the two more rearward locations cast more light onto the shearer picks. With support B, again with all supports illuminated, location on the side of the front legs illuminated more visual attention areas although it cast more shadows onto the travelway. Although locating the light source on the side of a front leg on support C cast more light onto the cable handler, the loss of light into the travelway was more marked with support B, and the centre of the travelway would probably be a preferable location.

When luminaires were only placed on alternate supports, many of these differences were removed, and the centre of the travelway appeared to be generally the best location of those investigated. However, in many seam heights this location is undesirable because of other ergonomic considerations, particularly the projection of the luminaire into the travelway headroom and a compromise location may have to be adopted, depending upon the design of the support. Other solutions, such as flush-mounting of luminaires within the powered support, are not

TABLE 20

Assessment of Lighting on Different Visual Attention Areas

Face Supports	Lamp Position	Coalface	Shearer Drum		Controls	A.F.C.	Cable Handler	Travelway			
			Side	Picks				Roof	Base	Front Pede-stal	Rear Pede-stal
A Up to 105 cm	Top Dead Centre	* +	* +	*	* +			* +	* +	* +	* +
	Between Rear Legs	* +	* +	*	* +			* +	* +	* +	* +
	Side of Front Legs	* +	* +		* +			* +	* +		* +
B 105 - 150 cm	Top Dead Centre	* +	* +	*	* +	* +		* +	* +	* +	* +
	Between Rear Legs	* +	* +		* +	* +		* +	* +	* +	
	Side of Front Legs	* +	* +	*	* +	* +	*	* +	* +		* +
C 150+ cm	Top Dead Centre	* +	* +		* +	* +		* +	* +	* +	* +
	Between Rear Legs	* +	* +	*	* +			* +		* +	
	Side of Front Legs	* +	* +		* +	* +	*	* +			* +

* Criteria (see text) satisfied when every support illuminated
+ Criteria (see text) satisfied when every other support illuminated

TABLE 20.

generally viable for British models. This is because of the use of forepoles which are retractable into the roof of the powered support.

4.2.5 Conclusions A study of three alternate locations for powered support luminaires mounted on each or alternate supports has shown that there is little benefit to be obtained, in terms of areas illuminated, from locating luminaires on every support. Illumination of the cable handler and, on one type of support the AFC, was generally very poor whichever location was adopted. Of the locations tested, the centre of the travelway was generally the best although ergonomic aspects such as restricted headroom and the need to see the AFC and cable handler may necessitate the selection of an alternative location.

4.3 The Effect of Background Illumination on Peripheral Movement Awareness

4.3.1 Introduction During the surveys of visual requirements (Section 3.1.1) it was hypothesised that a low level (5 lux) of ambient lighting could improve the detection of objects in the peripheral field of view over the detection possible with a cap lamp as the sole source of light. In order to investigate whether such an illumination level would increase peripheral awareness significantly, the detection of objects moving into the field of view was compared for different lighting conditions.

4.3.2 Apparatus A modification of the Keystone Periometer (Keystone View Inc.) was constructed to enable peripheral vision to be measured whilst the subject was wearing a safety helmet and cap lamp. His head was held steady by a chin rest and the periometer arm, pivoted above his eyes, was supported from the rear. The target holder of the periometer moved in a horizontal plane in line with the eyes. All readings were taken against a black (4% reflectance) background.

4.3.3 Method Six young adult male subjects, with normal uncorrected vision were used for the experiments. After an adaptation period of 45 minutes, the subject was seated with his head positioned on the chin rest, and instructed to fixate his gaze on a white arrow, 1.5 m away, in the centre of his visual field. Targets were presented in the peripheral field three times to each eye in a random order. Eight targets were used. Each was a rectangular card, 15 mm by 20 mm made from a British

Standard Institute Paint Colour Chart (British Standard Institute, 1972). The reflectances of the targets were in the range 6% - 72% and were chosen to correspond with the reflectances of surfaces commonly found underground (Table 21).

Peripheral movement perception was measured by recording the angle at which the target was first detected by the subject as it moved into the peripheral field, taking the mean of three readings. This procedure was followed in four lighting environments:-

a) Cap lamp only;
b) Cap lamp + 5 lux ambient illumination;
c) 5 lux ambient illumination;
d) Daylight conditions of 450 lux (control).

The lighting environments were presented to each subject in a randomised order with at least 24 hours between trials.

TABLE 21

Reflectances of Targets used in Peripheral Vision Testing and Comparable Surfaces Underground

Target Reflectances	Similar Underground Reflectances	
6% (Rust Red) 6% (Dark Grey)	Rust	9%
20%	Steel lagging board	20%
30%	NCB Overalls	30%
42%		
49%	Wooden Chock Block (new)	50%
64%	Stone Dust	63%
72%	New White Paint	74%

4.3.4 Results Initial four-way analysis of variance (subjects x targets x conditions x eyes) revealed a series of complex interactions involving factor D (left and right eyes). Subsequently two, three-way analyses of variance were carried out, treating the data for each eye separately. These both showed significant main effects due to factors B (targets) and C (conditions). However, analyses also identified a highly significant single-order interaction between factor C and factor A (subjects). In order to identify individual effects within these overall changes, Duncan Multiple Range Tests (Hicks, 1964) were carried out, analysing factor C separately for each subject because of the A x C interaction.

a) Lighting Conditions (Factor C) For all subjects, the angles of peripheral movement perception for the cap lamp + 5 lux condition and the control condition were always greater than for just the cap lamp. Table 22 shows the significance levels for these comparisons. As can be seen from the overall mean angles for all subjects and both eyes, shown in Table 23, the angle of peripheral movement perception in the 5 lux only condition was between these two groups. It was not consistently significantly different from either of them.

b) Targets (Factor B) For both eyes, the angle of peripheral movement perception for targets 5 - 8 (42% - 72%) was significantly greater than that for targets 1 and 2 (6%) with the exception of target 6 (49%) with the right eye which, although greater than both targets, failed to reach significance with target 2. Targets 3 and 4 (20% and 30%) did not show any consistent differences. Table 24 shows the overall means of peripheral vision angle for all targets for both eyes.

4.3.5 Discussion The results indicate that adding a low level of background illumination to the illumination provided by a cap lamp significantly improves peripheral vision, thus confirming the hypothesis formed during underground investigations. An object moving into the field of view could be detected an average of 9° sooner with the supplementary lighting. Similarly, increasing the reflectance of the same size and shape object also improved peripheral vision. A white object (72% reflectance) was seen 6 - 8° sooner than the same object coloured dark grey (6%) or rust-coloured (6%).

Eye dominance was found to exist in all subjects. Fischer and Cox (1974) demonstrated the existence of a dominant eye in general vision although no specific reference was made to peripheral vision. A similar dominance was identified during the testing of the visual abilities of 100 miners (Section 5).

TABLE 22

Statistical Comparisons of Peripheral Vision Angle, Cap Lamp only vs Cap Lamp + 5 lux and vs 450 lux Significance Levels

Subject	Probability Levels			
	vs Cap Lamp + 5 lux		vs 450 lux	
	Left Eye	Right Eye	Left Eye	Right Eye
1	.01	.01	.01	.01
2	.01	.01	.01	.01
3	.01	n.s.	.01	.01
4	.01	.05	.01	.05
5	.01	.01	.01	.01
6	.05	.01	.01	.01

n.s. - not significant

TABLE 23

Overall Means of Peripheral Vision Angles for Each Condition

Lighting Condition	Mean Angle
Cap Lamp only	86^{o}
Cap Lamp + 5 lux	95^{o}
5 lux only	92^{o}
450 lux (control)	100^{o}

TABLE 24

Overall Means of Peripheral Vision Angle for each Target, Left and Right Eyes

Target Reflectance	Peripheral Vision Angle (degrees)	
	Left Eye	Right Eye
6%	91^{o}	88^{o}
6%	90^{o}	90^{o}
20%	94^{o}	88^{o}
30%	95^{o}	90^{o}
42%	96^{o}	94^{o}
49%	95^{o}	92^{o}
64%	97^{o}	95^{o}
72%	97^{o}	96^{o}

4.3.6 Conclusions The addition of a low level of background illumination improves peripheral movement awareness significantly. Similarly, a high reflectance object, moving into the peripheral field, can be seen significantly earlier than a very low reflectance object. The maintenance of mobile equipment such as mine cars, locomotives, etc. in a high reflectance colour would therefore increase the probability of their detection in most circumstances. Although white gloss paint is generally used, it was suggested that environments which could have a large white content, such as a well stone-dusted, whitewashed roadway, yellow is a suitable, or even preferable, alternative.

4.4 An Investigation of the Effect of Light from a Cap Lamp on Depth Perception

4.4.1 Introduction Reports obtained during underground investigations (Section 3.1.1) suggested that visibility was affected when the source of light underground was a cap lamp in its normally worn position on the head. Because the line of the beam of light is virtually identical to the wearer's line of sight, minimum amounts of shadow are cast in the field of view from any visual target. This removes an important source of task/background contrast, which is particularly important in mining operations where other sources of contrast such as colour differences, reflecting ability and light level differences tend to be absent or minimal.

Consequently, it was frequently reported by miners that it was difficult to judge the precise height, distance or depth of some visual attention areas, e.g. cables or other equipment which had to be cleared safely in passing.

A study was designed to investigate the extent of this phenomenon under laboratory conditions.

4.4.2 Description of Apparatus A frame was built, 1.125 m in length and 0.75 m square, and covered on the inside with low-reflectance black paper to produce a visual environment in which visual cues, e.g. of distance and orientation, were reduced to a minimum. The end of the frame nearest to the visual targets had a removable flap which enabled the experimenter to obscure the observer's vision whilst the stimulus condition was altered. Two supports were used; one acted as a chin-rest whilst the other fixed the height of the cap lamp to ensure that the subject's line of sight was maintained at a central position with respect to the tunnel. Lateral movement of the subject's head was prevented by provision of two rods which clamped the helmet in position. The frame was supported on legs 1.0 m in height. Two identical 20 mm diameter rods, 2 m in length and coated with paint of 50% reflectance were placed at the opposite end of the tunnel to the subject, at a distance of 2.5 m from the observer's eyes, and 0.14 m apart, a distance which allowed both of them to be viewed simultaneously without movement of the head and also ensured that both rods received equal amounts of light from the cap lamp. The rods were supported by two wooden blocks marked with distance scales to enable the rods to be separated with respect to each other. The scales were marked at intervals of 20 mm.

4.4.3 Procedure The experiment was conducted in a laboratory in which all light was excluded. The subject sat at the end of the tunnel furthest away from the visual targets. The seat and restraining bars were adjusted so as to hold the subject's head and cap lamp in a constant position. It was ensured that subjects could only see central parts of the visual targets through the tunnel. The general lighting was then switched off.

The subject was asked to indicate which pole he considered to be nearest to him.

The position of the right-hand pole was altered between each presentation. It was placed 0, 2, 4, 6, 8 or 10 centimetres further away or nearer to the subject than the left-hand pole. Each condition was presented ten times in a random order for each subject, a total of 110 stimulus presentations. After the subject had been allowed to view the targets for a maximum period of five seconds, and his response recorded, the end of the frame was covered whilst the next stimulus presentation was prepared. Each experimental session lasted approximately twenty minutes. The stereoscopic vision of all subjects was established as normal.

4.4.4 Results The first two subjects made 100% correct responses even at the smallest spacings of 2 centimetres with no difficulty. As the judgements required may have been simplified by the relative brightness of the visual targets, it was decided to modify the experiment by reducing the reflectance of the targets to 11%. Two different subjects participated in the modified experiment and, again, scored 100% correct responses.

4.4.5 Discussion The experiment did not succeed in demonstrating any problem in the perception of relative depth with the cap lamp as the sole source of light. However, the frequency of occurrence of reports of such problems amongst miners interviewed suggested that there was a genuine effect but that the laboratory experiment had failed to reproduce it. Two major contributing factors can be identified; other visual cues and viewing time.

During the experiment, the subjects became aware that the two targets were the same diameter and reflectance. Consequently, they were able to use relative brightness and size cues to determine the relative position of the two targets. In addition, subjects were allowed a maximum of five seconds viewing time.

Information is normally obtained from the environment by brief scanning movements, when individual areas in the field of view may only be viewed for a fraction of a second. In the present experiment, subjects were aware that all might not be what it initially seemed to be and consequently allowed themselves more time to sample all the available information when the discriminations needed became more difficult, thus avoiding errors.

4.4.6 Conclusions Although visual problems associated with inadequate depth perception were widely reported by miners (see Section 3), experimentation failed to reproduce this effect. The visual problem is clearly more complex than that produced in the laboratory and the work described above indicates the difficulties in attempting to reproduce such a situation with so many of the relevant variables absent.

4.5 A Study of the High Reflection Materials Available for Use on Miners' Donkey Jackets

4.5.1 Introduction Studies of the visual requirements for machine drivers (Section 3.3) identified the need to see potential obstructions including objects lying in the roadway, and more importantly, miners who may be injured. The ease with which miners can be seen is a function of the light reflected back by the miners clothing from the headlight beam.

One item of protective clothing issued to some miners is a donkey jacket made from a blue/black melton cloth. This fabric has a very low reflectance and the jackets are supplied with bands of high reflectance material sewn to the sleeves and yokes. A number of these materials are commercially available and, in conjunction with the National Coal Board Working Party on Protective Clothing, a study was carried out on these to identify the best materials for this application. All materials assessed were constructed of bonded spheres attached to a durable backing. Tests were conducted to assess the levels of brightness produced by the materials from the light of locomotive headlamps, changes in these levels produced by varying the angle of incidence and differences produced by wear.

4.5.2 Method Luminance levels were determined for all samples, 40 m from the light source at five angles of incidence from 0° to 60°. Identical tests were conducted on samples of the same materials which had been worn underground for a period of six months. Two lamps were used (X and Y) producing different light levels (13.58 lux and 0.45 lux respectively at 40 m) to determine whether differences in incident light levels had any effect on the relative order of materials.

4.5.3 Results Table 25 shows the luminance values obtained using lamp X. Lamp Y did not produce any differences in order between materials.

4.5.4 Discussion The visual discrimination between an object and its background is partly a function of their relative brightness. The worst luminance obtained for lamp X was 2.2 cd m^{-2} from an old sample of material 2 at 60°. This can be compared with the estimated luminance of a coal dust covered floor at the same distance and light level of 0.007 candela m^{-2}. The contrast ratio, calculated from these two values, is 0.99 which means that, even when worn, this material would still be visible against its background.

The best materials retained their advantage over the other materials even when worn. However, some other materials wore less well, for example, when measured at 0°, the third best material when new (5) became the sixth best when worn.

4.5.5 Conclusions The study identified two materials as the best for use as reflective strips on protective clothing. It demonstrated the need to consider a variety of angles of incidence of light in assessing

TABLE 25

TABLE 25

Levels of Luminance Recorded under all Test Conditions (Lamp X)

Material	Brightness of Material (cd m^{-2})									
	New Samples					Worn Samples				
	Angle of Incidence									
	0	15	30	45	60	0	15	30	45	60
1	98.4	95.0	87.1	33.9	5.8	101.8	83.8	46.0	10.3	5.3
2	87.9	86.0	63.8	21.7	5.6	36.0	31.9	21.9	8.0	2.2
3	69.2	68.3	77.4	65.2	44.5	55.5	44.1	31.5	21.3	10.2
4	107.1	96.4	74.2	11.3	4.6	87.8	75.1	34.4	12.2	3.4
5	119.5	108.6	93.7	29.8	5.43	83.2	65.6	40.1	16.2	7.1
6	225.4	249.9	275.7	259.4	67.9	168.3	159.1	161.7	149.4	39.3
7	55.1	55.1	51.7	44.7	37.4	13.8	13.0	10.1	8.4	8.8
8	25.6	26.3	30.5	29.7	18.3	21.9	20.4	17.3	16.3	11.9
9	461.7	329.9	186.7	83.5	249.9	382.3	321.1	153.0	39.4	172.8
10	107.1	96.4	74.5	11.3	4.6	87.9	75.1	34.4	12.2	3.4

such materials and the way in which they retained their brightness with age.

These reflective strips are generally supplied firmly sewn to the garment. However, wear of the reflective strip may reduce the useful life of the garment and some means of replacing the strips would be desirable.

The results of this study were reported to the Working Party on Protective Clothing which now recommends the provision of replaceable armbands made from either of the two materials identified.

5. VISUAL ABILITIES OF UNDERGROUND WORKERS

The required lighting levels for a task are a function of the visual requirements of that task and the visual abilities of those concerned. Sections 2 and 3 showed that although light levels underground were generally low in comparison with those experienced on the surface, the levels were not considered to be a visual problem for many of the visual activities undertaken. These assessments were based on the assumption that the mining population has comparable visual abilities to the normal working population. To verify this, a study was established to examine the visual abilities of miners, assess the results in conjunction with tests on other industrial populations and, if necessary, modify any requirements for lighting levels as appropriate.

Studies of visual abilities which have been published, generally provide information on the basis of passing or failing standard visual screening tests with little information regarding the detail of these failures or of the test criteria adopted. (The latter may be set according to the occupational needs). The Optical Information Council conducted a survey of 20,000 people over an 11-month period (Optical Information Council, 1969). It was reported that 69% of those tested were male and, of these, 44.5% failed on one or more aspects of the screening test used. (A slightly lower proportion of females failed (42.6%)). Cross (1970), reported a number of studies, breaking down the information according to specific industries. Referrals ranged from 20% (textile workers) to 51% (perfumery company). Figures were also reported from a survey of the visual abilities of over seven million American citizens, carried out by Bausch and Lomb, the manufacturers of a vision screening instrument. The average referral rate was 40% within a range of 14% (general manufacturing) to 75% (coal miners). One of the major factors influencing visual abilities is age. One study reported by Cross (op cit) provided a breakdown of referral rate according to age. These figures together with data from two surveys reported by the Industrial Visual Welfare Group of the North London Association of Opticians (P T Stone, Loughborough University, personal communication) are given in Table 26. The referrals from these studies were based on the specific task requirements for each individual and a high proportion of 26 - 35 years old bedding factory employees were regarded as requiring a particularly high level of visual acuity. Apart from such anomalies, the figures show the general decrease in visual abilities with age.

TABLE 26

Referral Rate for Visual Screening Tests according to Age Group

Occupation	Age Group					Total
	Up to 25	26 - 35	36 - 45	46 - 55	56 and over	
Bedding Factory	32%	64%	44%	56%	57%	46%
Foundry	0%	37%		35%	63%	44%
Perfumery	38%	42%		75%	86%	51%

5.1 Visual Screening - Miners

5.1.1 Procedure A sample of 101 miners, employed by the National Coal Board were selected as subjects for this study. Subjects were selected to provide an age distribution comparable to national employment figures within the industry. Table 27 shows this age distribution. Each subject participated in a standard visual screening test (Keystone View Inc). Unlike many of the other surveys reported above, no reference was made to the visual task requirements of each individual in determining failure. This effectively made the test more severe as subjects could fail on, for example, stereopsis or colour vision; whether or not stereopsis was regarded as a prerequisite for their job.

TABLE 27

Age Distribution of Subjects

Age Range (years)	Number of Subjects
Under 20	5
20 - 29	18
30 - 39	22
40 - 49	24
50 - 59	30
60 and over	2

5.1.2 Results Following expert advice (P. Ungar, Keystone View Inc., personal communication) failure to meet near or far fusion criteria was not regarded as a test failure because this was regarded as unlikely to influence visual performance. Four of the 101 subjects had previously been diagnosed as requiring glasses but failed to bring them on the day of the test. These were consequently excluded from subsequent analyses. Table 28 shows the failure rate on the visual screening test, categorised into the same categories as used in Table 26 to facilitate comparison.

TABLE 28

Referral Rate from Visual Screening, according to Age Group

Age Group					
Up to 25	26 - 35	36 - 45	46 - 55	56 and Over	Total
21%	30%	23%	33%	53%	32%

5.1.3 Discussion The results show that 32% of miners failed the visual screening test. This compares favourably with the results quoted from other industries being less than the national average of 44.5%, and considerably lower than the value of 75% quoted for American coal miners. The referral rates demonstrate the general trend for a decrease in visual abilities with increasing age, again in line with values for other industries.

5.2 Conclusions

The study showed that the visual abilities of coal miners were comparable to those in other industries and therefore that no special adjustments were necessary to any recommended light levels based on general population requirements.

6. VISUAL ENVIRONMENTS AND LIGHTING STANDARDS IN COAL PREPARATION PLANTS

A study was set up to evaluate the provision and requirements for lighting in coal preparation plants and, where appropriate, to provide guidelines for the development of new criteria for acceptable light levels. It was established in conjunction with the sub-committee on illumination of the joint *NCB/ABMEC/CPPA environmental group which was examining complaints from coal preparation plant workers regarding the levels of lighting provided at newly commissioned plants.

6.1 Light Levels

6.1.1 Light Levels Measured at Coal Preparation Plants Light levels were measured at nine coal preparation plants to determine the range of light levels currently provided. Table 29 shows the range and median values obtained during day and night shifts at a variety of locations.

6.1.2 Recommended Light Levels Recommended standards were introduced in 1969 (National Coal Board, 1969) to replace those introduced in 1954. Table 30 lists these values. More recently, the Illuminating Engineering Society (IES) recommended lighting levels for coal preparation plants for picking belts, working areas and other areas (Illuminating Engineering Society, 1977). These can be supplemented by values for other industries within the code. Table 31 shows the values obtained.

TABLE 29

Range and Median Light Levels recorded at a Variety of Locations at Nine Coal Preparation Plants

	Light Levels (lux)			
	Day Shift		Night Shift	
Location	Range	Median	Range	Median
Picking belts	5 - 7,000	260	21 - 425	100
Control rooms Sub-stations	35 - 650	228	15 - 200	68
Other working areas	2 - 8500	120	0.5 - 404	85
Conveyors, stair gantries, walkways	2 - 854	87	1 - 260	35

* National Coal Board/Association of British Mining Equipment Companies/ Coal Preparation Plant Association

TABLE 30

National Coal Board, Recommended Minimum Light Levels for Coal Preparation Plants

Area	Illumination (lux)
Picking Belts	215
Other Working Areas	108
Conveyors, stairs, gantries, walkways	22

TABLE 31

Illuminating Engineering Society, Recommended Light Levels for Coal Preparation Plants and Related Industries

Area	Illumination (lux)
Picking Belts	500
Sub-stations	100
Control Rooms	300
Working Areas	300
Other Areas	150
Stairs, gangways	150
Industrial covered ways	50
Gantries	100

6.1.3 Comparison of Measured and Recommended Light Levels A comparison of the various tables shows that although in daylight the median values for existing light levels exceeded the National Coal Board minimum levels, the wide spread of data around these medians meant that the lighting of a number of locations was below the recommended minima. The IES values, described as satisfactory light levels (rather than minimum or optimum values), were generally greater than the median values recorded, although all areas had some levels which exceeded the recommendations.

All median light levels obtained during night-shifts were below either recommended set of values with the exception of the National Coal Board minimum for conveyors, etc.. The IES value for picking belts was greater than any light levels measured on picking belts at night. Other areas had a wide spread of values, some of which exceeded the recommendations.

The general picture to emerge from this was that, particularly at night, task visibility could be improved in a number of locations by the addition of lighting to raise levels above the National Coal Board minima. However, subjective reports from coal preparation plant operatives have shown that, even where these values were exceeded, the task visibility on a number of occasions was still regarded as unsatisfactory. Further investigations were therefore carried out to produce alternative criteria for the lighting environments, by systematically assessing subjective opinions of light levels and surveying other factors which represent good lighting practice.

6.2 The Subjective Rating of Task Visibility, Related to Light Levels in Coal Preparation Plants

6.2.1 Method A number of individual task components (visual attention areas) were identified at each of seven coal preparation plants.

Observer teams were selected from three National Coal Board Areas; these included plant operatives and officials, maintenance staff, and area officials. The teams visited each plant twice (daylight and night-time) and were conducted around the plant. Team members were each asked to rate how easily they could see each visual task in turn, on a five-point rating scale - "very difficult", "difficult", "moderate", "easy" and "very easy". The light level incident on the visual attention area at the time of rating was recorded. Appendix 2 shows the questionnaire used at one plant.

The percentage of observers responding to visual tasks in "easy" or "very easy" categories was then plotted against the incident light levels recorded at all examples of that task.

6.2.2 <u>Results</u> Figures 13 and 14 show the results under day and night conditions for one task category (walkways). The fluctuations on both graphs show the influence of factors other than light levels on task visibility.

6.2.3 <u>Factors other than Light Levels Influencing Observer Responses</u> Subsequent surveys investigated all the factors contributing to the anomalies in observer response described above.

6.2.3.1 <u>Light Level Variation</u> Large light level variations existed between adjacent areas of individual plants. During the day, the major factor causing these variations was the dominance of natural light over the lighting system. Light level differences up to 15,000 lux were recorded between adjacent work areas where direct sunlight influenced light levels.

6.2.3.2 <u>Contrast and Light-Reflecting Power</u> Poor contrast in the field of view was also a major cause of reduced discrimination between a visual attention area and its surroundings. This was especially relevant on walkways and stairs (particularly handrails) and in differentiating machine areas from adjoining areas. This can constitute a safety hazard and is commonly alleviated by delineating such areas by painting high contrast borders, e.g. on the edge of steps or around machinery. However, if these borders are not regularly renewed or coal dust or slurry is allowed to obscure them, reduced task visibility can result, even in brightly illuminated areas.

6.2.3.3 <u>Glare</u> Glare in the field of view was another factor contributing to poor task visibility, particularly during the day. Windows were often placed so that, especially on the higher areas of the multi-storey plants, controls were viewed either directly against or adjacent to windows. Particularly on bright days, this produced a very high brightness relative to interior surfaces, leading to discomfort glare, a general problem identified by coal preparation plant operatives.

6.3 <u>Conclusions</u> A large-scale subjective response survey was conducted which identified incident light levels for a range of visual tasks which were

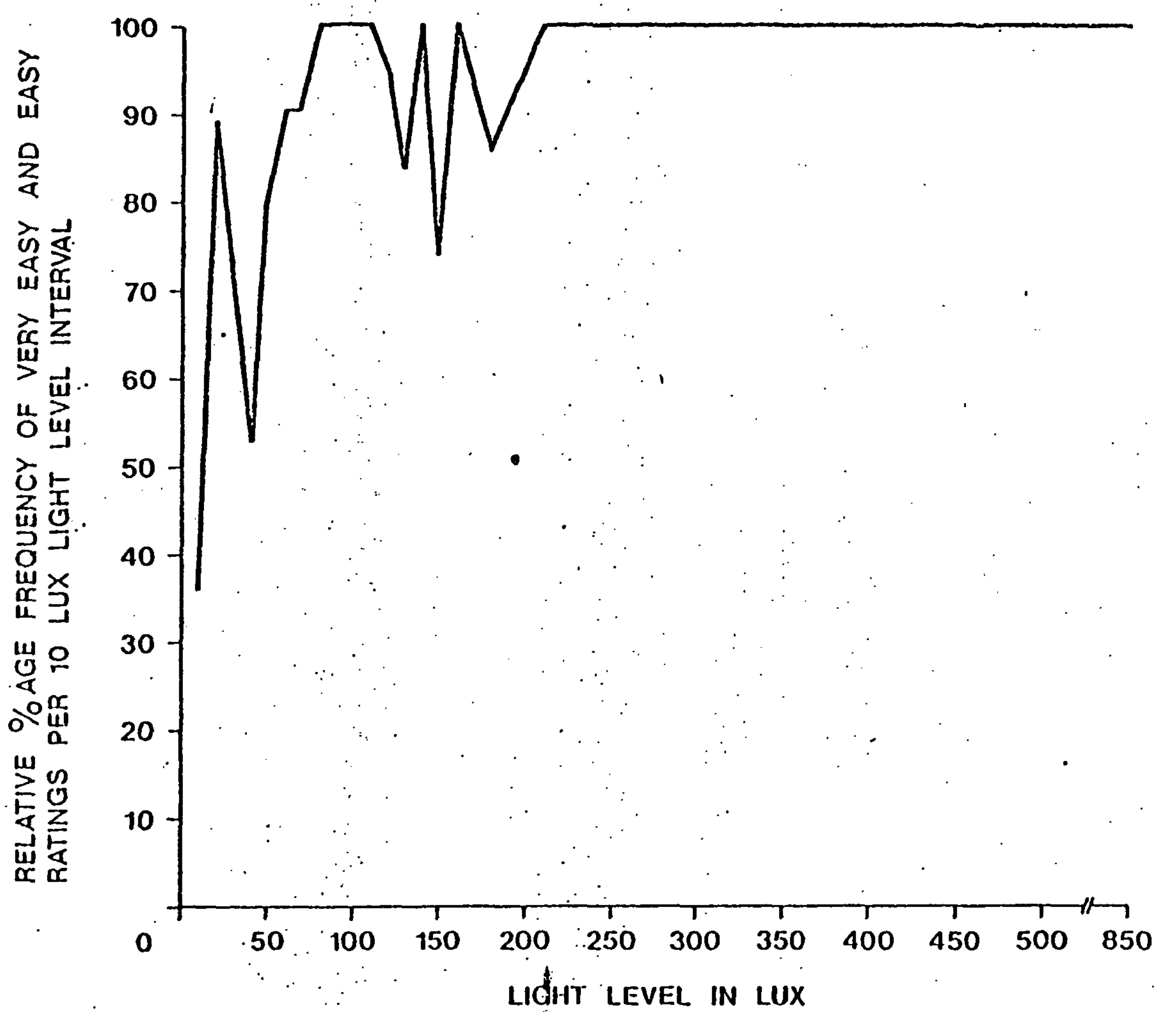


FIGURE 13 - Observer Responses to Visibility of Walkways Related to Light Levels - Dayshift

FIGURE 14.

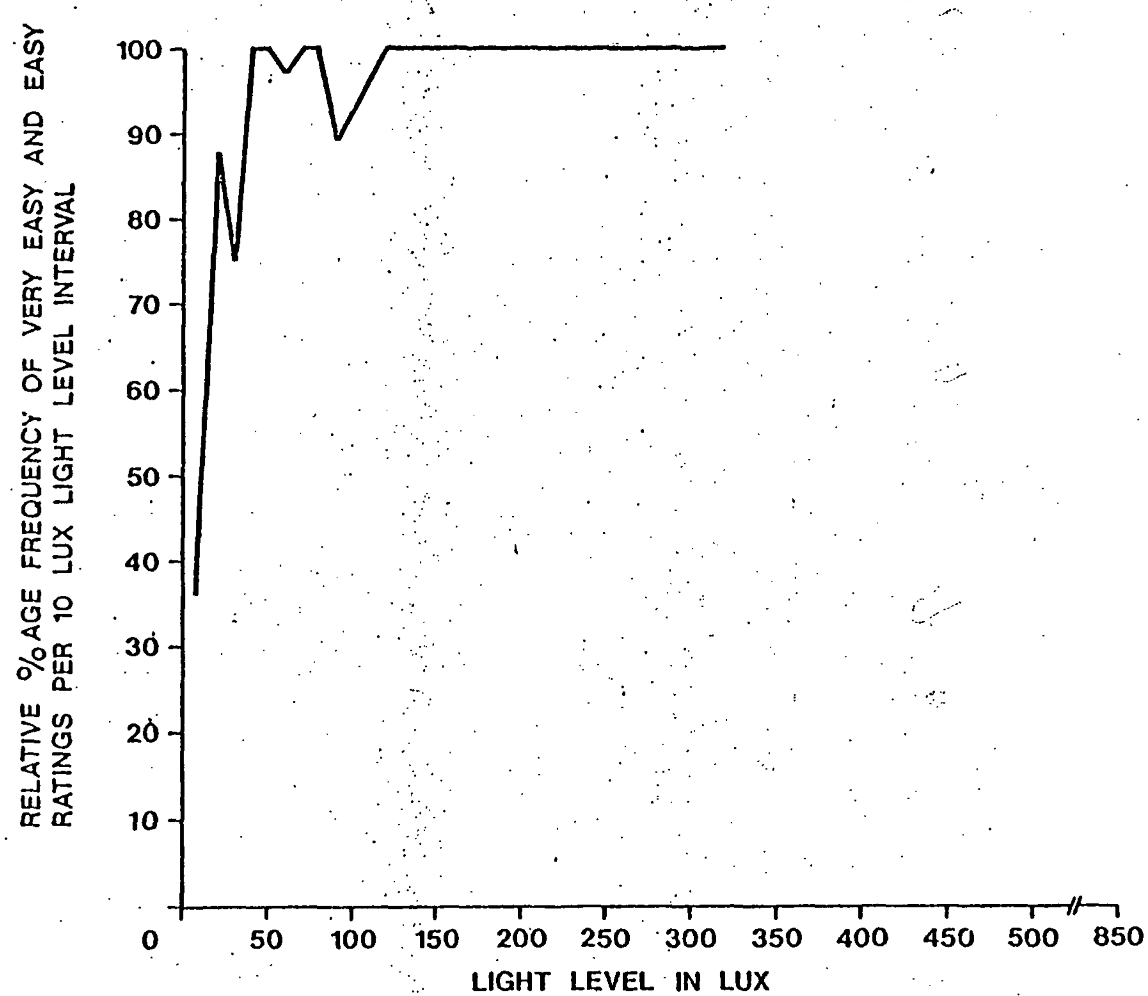


FIGURE 14 - Observer Responses to Visibility of Walkways Related to Light Levels - Nightshift

acceptable to observers under day and night conditions. The results indicated that lower light levels were acceptable during the night than during the day and that widely differing light levels were acceptable during daytime for the same type of visual tasks. This confirmed initial impressions that factors other than actual light levels were important.

Subsequent surveys investigated the other factors involved. These included:-

a) Reduced contrast vision because of dirt and worn paint in a number of areas including handrails, steps, border areas of machinery. Where contrast enhancement had been used (e.g. freshly painted handrails), the light levels judged as adequate by the observer teams were generally lower than under other circumstances.

b) Glare from windows, on occasions when they were positioned so that only the sky was visible, was a cause of reduced visibility of adjacent areas whose lower general surface brightness made them appear in shadow by comparison. Adaptation problems were also likely where large light level variations occurred at adjacent areas.

c) The coal preparation plant environment which includes problems of vibration of plant, moisture and dirt, tended to reduce the working life of luminaires.

d) The problem of reduced working life of luminaires was exacerbated by inaccessibility to some lamps which caused difficulties for their efficient maintenance and cleaning.

The results of all surveys were presented to the NCB/ABMEC/CPPA Committee referred to earlier, and will serve as the basis for new criteria for lighting installations.

7. GENERAL CONCLUSIONS

There was no evidence to support previous reports in the literature that the visual abilities of a sample of mineworkers were worse than the general industrial population.

7.1 Mains Lighting

7.1.1 Limitations to Existing Mains Lighting

In many locations observed, levels of illumination from mains lighting were below the recommendations published by NCB (1974). However, in most areas the actual light levels themselves were not regarded as a limiting factor for visual requirements.

Distribution of light as shown by diversity ratios was a major limiting factor. Many areas supplied with mains lighting, including the face and face end, failed to comply with the 5:1 ratio recommended for good uniformity. Numerous other areas, for example pit bottoms and roadways, were adequate in this respect.

One of the major contributing factors to the effectiveness of light distribution was the location of the luminaires. This was of particular importance with tubular fluorescent lamps as the light distribution from them is asymmetrical. Of the several locations observed in roadways, the positioning of luminaires on alternate walls was found to be optimum in terms of physical distribution of light and from a functional assessment of its utility to visual tasks. In particular, this arrangement appeared to improve miners' visibility when they walked in the roadway side, as when accompanying mine cars, and helped in the execution of such tasks as placing of lockers in mine car wheels since these areas were then directly illuminated.

Insufficient luminaires also contributed to the problem of distribution at other special visual task areas in roadways. These included supplies areas, mine car coupling/uncoupling areas, e.g. at pit bottoms, and areas such as transfer points where steps and walkways (notably under belts) were often in shadow. Illumination at points of limited headroom would have improved visibility in many places.

Specific tasks in other areas were affected by luminaire location. At face ends, luminaires positioned above the switchgear put displays on the vertical front surfaces into shadow and also ensured that only minimum illumination reached the roadway surface alongside. Luminaire systems designed to be placed over the roadway would have improved illumination of both areas.

A number of different locations of luminaires were seen on powered supports, all of which adequately illuminated the travelway but failed to illuminate task areas in front of the powered supports. The difficulties of placing the luminaires elsewhere were recognised but the provision, in the future, of integrated luminaire/powered support systems is recommended. A technique was established which used model powered supports to investigate the effects on light distribution of luminaires mounted in alternative positions. This technique showed there to be little advantage to be gained from having luminaires on every support.

Limitations to the effectiveness of the available mains lighting system also resulted from other factors. Accumulations of dust on luminaires resulted in up to a 50% reduction in light output from a single luminaire. Wellglass luminaires appeared to collect more dust than tubular luminaires, and the latter collected more dust when placed at right angles to the roadway. An indirect effect on light distribution was the treating of roadway and wall surfaces. Stonedusting and whitewashing were found to increase reflected light by up to a factor of 18 over untreated surfaces.

7.1.2 Benefits of Existing Mains Lighting Mains lighting provided a number of benefits to miners, where it existed:-

a) Rope Haulage: Improved visibility was provided of the relative locations of supplies, mine cars and hazards under-foot when loading/unloading. Mains lighting provided improved visibility of mine car wheels and the general roadside area, provided that luminaires were positioned on alternate walls as described above.

b) Locomotive Haulage: Mains lighting provided sufficient illumination within the cab during transit to adequately illuminate displays and controls which were otherwise unilluminated (see below on cap lamp light). Light from mains luminaires was reflected in locomotive rails and clearly showed obstructions lying on them by producing a dark area on the rail. Distance vision was improved as was awareness of the extremities of the roadway area, e.g. walls and roof.

c) Face Shearer Operation: Mains lighting provided the shearer operator with improved contrast vision for face and roof profile control within the limits of distribution described above. It also provided for easier movement along the travelway.

d) <u>General Activity</u>: The general raising of luminance levels in the visual field, produced by mains lighting, reduced the glare and discomfort effects of point source of light such as cap lamps and locomotive headlamps. The ambient light produced also provided contrast vision of the various hazards to safe movement (e.g. rollers, sleepers under foot) by causing them to cast shadows. It was determined from field observation and experimentation (see below on headlamps and cap lamps) that a minimum ambient illumination level of 5 lux would significantly improve the detection of primary and secondary targets by:-

i) improving peripheral awareness;
ii) improving contrast vision;
iii) reducing or eliminating inaccuracies of depth perception.

This minimum level would best be achieved through the use of low energy luminaires at regular, closely-spaced intervals rather than fewer high-energy luminaires. This would ensure a more even distribution of light. For example, the intrinsically safe units designed specifically for face lighting were observed in an another location where they provided a better lighting environment than higher energy, purpose-built luminaires.

7.2 Headlamps

Light levels from headlamps were generally very low at 60 m. Tests indicated that a level of 3 - 7 lux would be a reasonable minimum to allow detection of obstructions by locomotive drivers.

Light distribution (beam width) could limit visibility in curved roadways.

Location of headlamps on locomotives had little effect on light distribution for most types of luminaire.

Lower headlamp mounting heights may improve shadow contrast vision depending on the driver's eye height above the lamp. However, this must be weighed against other operational considerations, e.g. if used in shunting, mine cars may obstruct light.

Headlamp maintenance and cleaning was a problem, particularly on heading machines. This was largely because of the protective grills which hindered lens cleaning and required the use of special tools (normally kept in underground maintenance shops) to replace defective bulbs. Attention should be paid to designing lamps which simplified these tasks.

Particular attention should be paid to the location of headlamps at an early stage in the design of heading machines. Many examples have been reported (Mason et al, op cit) of ineffective headlamps because of inappropriate positioning of the units. This could result in shadow obscuring the working area, or glare problems for other people working in the vicinity. The provision of flood-type lamps on face end machines is recommended for further consideration.

7.3 Cap Lamps

The cap lamp provided adequate levels and distribution of light for close work.

Light provided by the cap lamp was less satisfactory for general movement and for distance work. This largely related to the point source nature of the cap lamp and its location, i.e. near to the eyes of the wearer. This produced problems in peripheral vision and probably depth perception.

It was determined that a minimal level of ambient illumination (5 lux) can produce a significant improvement in peripheral vision and, as suggested by the headlamp studies, would also benefit general activity, in particular the detection of obstructions at a distance.

Cap lamps were found to be inadequate for the illumination of displays and controls in locomotive cabs because of the reflected light produced in glass-covers and windscreens.

7.4 Other Considerations

Illumination of displays in cabs was not provided and the use of the driver's cap lamp for this purpose produced glare as described above. Kingsley et al (op cit) proposed the use of fibre optics as a method of internally illuminating displays and this method is currently being evaluated by National Coal Board engineers.

Consideration should be given to ensuring adequate all-round visibility for operators of mobile plant. Obstructions to lines of sight were of particular concern because of the operation of large mobile machinery in confined spaces. Guidelines for machine design to cater for this are contained in Kingsley et al (op cit) and Mason et al (op cit).

Many reflective materials are commercially available for use on protective clothing. These vary considerably in the angle over which they are effective and in their durability. Two materials were identified as the result of a series of tests (Section 4.5) and these are now recommended by the National Coal Board for use on its protective clothing. Because the wear tests demonstrated that the useful life of these materials was less than that of the garments, it has also been recommended that the reflective materials should be provided in the form of replaceable arm-bands.

7.5 Coal Preparation Plant Lighting

A subjective assessment technique which used experienced plant operatives and officials to form observer teams was established to assess illumination levels in coal preparation plants.

The overall levels of illumination were not found to be the major source of dissatisfaction with lighting environments. Light level variation was a major limitation to visibility. This resulted in conditions where light levels were regarded as unsatisfactory even though far in excess of the Illuminating Engineering Society recommendations and, conversely, situations where light levels less than the recommendations were considered to be satisfactory.

Glare due to natural light was a major cause of dissatisfaction. Some visual attention areas had to be viewed against, or adjacent to, windows through which only the sky was visible. This led to discomfort glare, particularly on bright days.

Natural light also contributed to the high illumination differences mentioned above.

Poor contrast in the field of view was another major cause of reduced discrimination between a visual attention area and its surroundings.

This can be improved by delineating such areas by painting high contrast borders, e.g. on the edge of steps.

Attention should be paid to the utility of task lighting to improve the visibility of specific visual attention areas without the expense of increasing general illumination.

Illumination levels were frequently reduced from those intended because of maintenance and cleaning problems. Lighting installations should be designed for easy access to luminaires.

8. ACKNOWLEDGEMENTS

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South Midlands Area

- Baddesley Colliery
- Bagworth Colliery
- Daw Mill Colliery
- Donisthorpe Colliery
- Rawdon Colliery
- South Leicester Colliery
- Tilmanstone Colliery

South Yorkshire Area

- Dinnington Colliery
- Manton Colliery
- Thurcroft Colliery

Western Area

- Bold Colliery
- Littleton Colliery
- Holditch Colliery

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APPENDIX 1

Method of Visual Task Analysis and Problem Identification

Each job analysed was divided into a number of specific areas of attention (visual attention areas). These were identified by direct observation and interviews with miners. Each visual attention area was studied in detail, and miners interviewed, to identify visual problems. Problems identified, including visual problems from causes other than lighting (e.g. lines of sight), were recorded, together with other details, on a visual task analysis sheet (Figure 1). The terms used were defined as follows:-

Lines of Sight

This category was used to describe limits to visibility resulting from the operating position for a job. The sub-categories below were used as a refinement of this technique:-

a) Objects in Way
This category was used if there was an obstruction between the operator and the visual attention area. For example, there can be powered support legs between the operating position and the AFC that the operator requires to see.

b) Interaction
This term was used when there were visual attention areas which could be seen from the same operating position, but this involved major postural changes, i.e. head and/or body was required to be turned through more than 180° and/or there was more than one visual attention area which had to be sampled during the specific operator task.

c) Conflict
This term was used in the situation where there was more than one visual attention area of equal importance that had to be observed during that specific operator task, and the operative had to move his position to sample the attention areas as necessary. For example, during heading machine operations there may be cases where, although an operator seated at the controls is able to see the cutting head adequately, he will have to stand up to see where the rip falls so that it can be more efficiently

FIGURE 1 - VISUAL TASK ANALYSIS SHEET USED DURING SURVEYS

PIT:	JOB:		LOCATION:
SHIFT:	DATE:		OBSERVER:
VAA NO.:	POSSIBLE LIMITATIONS:		COMMENTS:
VAA Description (Size, Distance, Detail - Large, Medium, Fine, Mixture)	1. Lines of Sight		
	Objects in way		
	Interaction		
	Conflict		
	2. Task Size/ Distance		
	3. Light Effects		
	Distribution		
	Contrast		
	Glare		
Reasons for Viewing	Shadow		
	Shadow Relief		
	Depth Perception		
	Levels		
	4. Operator Position		
	Scope for Movement		
	Implication for Safety		
Lighting System	5. Environmental Factors		
	Water Sprays		
	Dust		
	6. Interaction Effects		
	Time		
	Transient Adaptation		
	Peripheral Awareness		

collected.

Task Size/Distance

This category was used to describe the situation where a combination of the size of the visual attention area and/or its distance from the operator could result in a visual problem even under optimum lighting conditions. For example, an ammeter dial placed too far away to be visible to an operator who was in a fixed operating position.

Light Effects

a) Distribution

This term was used to explain the effects of light spread and to identify the visual problem when light sources were too few or were spaced too far apart to provide reasonably uniform light. A major example in some work areas was the cap lamp which, as a spot light source, was only able to produce a narrow beam of light with levels declining rapidly along its length and and to each side. Also, examples existed of transfer points or motor houses where only one lamp was used to light the area, which could be a visual limitation under some circumstances. This effect has also been described as the "diversity ratio" of an installation (Roberts 1956, Bell 1965) and "uniformity ratio" (IES 1977).

b) Contrast

This term describes the effect when a visual attention area cannot be seen sufficiently well against its background. This may be because colours are very similar, e.g. a dirt band running through a seam of coal or because light levels are so low that any colour is not seen and shadows are too weak to create a sharp edge to the visual attention area in question.

c) Glare

This describes the effect produced when lights in the field of view are excessively bright. An example was the cap lamp which, when shining in the eyes of an oncoming person, could prevent him seeing the road beyond it, or it could make him turn his head away to avoid it.

d) Shadow

This category is used to describe the situation where a visual attention area is in shadow because of obstructions between it and the available lighting. An example was the armoured flexible conveyor, and sometimes the haulage chain, when they were put into shadow by obstruction caused to the face lighting by the powered supports.

e) Shadow Relief

This term was used to describe the effect created when only the cap lamp was available as a source of light. Due to its position on the head it was found that light from the cap lamp produced almost no shadow at the visual attention area in question. Under some circumstances, shadow is a very good visual aid, e.g. when walking along roadways where it allows uneven areas and items such as rollers and sleepers to be seen. It was found that almost any level of mains lighting removed the "no shadow" effect, as did the light from another cap lamp.

f) Depth Perception

This term was used to describe another effect produced by having only the cap lamp as a source of light. Due to the lack of shadow, described under (e), subjective impressions were that judgement could be affected about the precise height, distance, or depth of some visual attention areas, e.g. cables or other equipment which had to be cleared safely in passing.

g) Levels

This category was used when the lighting levels produced on a visual attention area were low enough to be considered a visual problem. An example used in the discussion is levels of light on the coal face from the travelway lighting. These were considered too low to adequately check the condition of the face. This was thought necessary by operators because of strata instability on the face surveyed.

Operator Position

This category was used to describe situations which arose because of the inability of an operator to move into a position where he could see a visual attention area more clearly. Sometimes it was because the operator was at a fixed operating position and could not move from it, but also the problem arose because of safety considerations, e.g. to look very far down the coal face would necessitate moving beyond the safety of the powered supports.

Environmental Factors

This category was used to describe situations where water spray or dust was a visual problem. An example was at the shearer drum or when looking along the face just after shot-firing had taken place.

Interaction Effects

This term described any visual limitation arising from interaction between visual attention areas within the whole task.

The results from individual visual attention area surveys were collated onto summary sheets (Figure 2) to show the problems associated with a complete job. Separate summary sheets were used for an evaluation with or without mains lighting. An asterisk was used to denote when the majority of those questioned for a specific task identified the existence of a particular visual limitation in a given visual attention area.

FIGURE 2.

Visual Limitations / Visual Attention Areas	Lines of Sight			Task Size/ Distance	Light Effects							Operator Position		Environmental Factors		Interaction Effects		
	Objects In Way	Interaction	Conflict		Distribution (cap lamp / general)	Contrast (cap lamp / general)	Glare (cap lamp / general)	Shadow (cap lamp / general)	Shadow Relief (cap lamp / general)	Depth perception (cap lamp / general)	Levels (cap lamp / general)	Scope For Movement	Implications for Safety	Water Spray	Dust	Time	Transient Adaptation	Peripheral Awareness

FIGURE 2

1. (a) Rate how easily you can see the left handrail between the white marks as you go down the stairs 006 - 009 Transfer point

☐	☐	☐	☐	☐
very easily	easily	moderately	difficult	very difficult

(b) Comments ______________________________

____

____

2. (a) Rate how easily you can see the floor between the white marks on the 009-016 walking area

☐	☐	☐	☐	☐
very easily	easily	moderately	difficult	very difficult

(b) Comments ______________________________

____

____

3. (a) Rate how easily you can see the stone, wood and other material from the coal on the picking belt

☐	☐	☐	☐	☐
very easily	easily	moderately	difficult	very difficult

(b) Comments ______________________________

____

____

4. (a) Rate how easily you can see the large lumps of coal blocking the Barker screen holes (ie pegging)

☐	☐	☐	☐	☐
very easily	easily	moderately	difficult	very difficult

(b) Comments ______________________________

____

____

5. (a) Rate how easily you can see the beam between the white marks at head height as you go outside from the Kue Ken crusher platform

☐	☐	☐	☐	☐
very easily	easily	moderately	difficult	very difficult

(b) Comments ______________________________

____

____

6. (a) Rate how easily you can see the 3rd step up on the stairs to the new BJD crushing scheme

☐	☐	☐	☐	☐
very easily	easily	moderately	difficult	very difficult

(b) Comments ______________________________

____

____

7. (a) Rate how easily you can see the right handrail between the two white marks on the stairs to the new BJD crushing scheme

☐	☐	☐	☐	☐
very easily	easily	moderately	difficult	very difficult

(b) Comments ______________________________

____

____

8. (a) Rate how easily you can see the floor between the two white marks (2nd-3rd fluorescent fitting) on the 023 conveyor Gantry

☐	☐	☐	☐	☐
very easily	easily	moderately	difficult	very difficult

(b) Comments ______________________________

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