Underground lighting in the gold mining industry

By C. H. VAN GRAAN,* M.Sc. (Pta.), J. S. GREYSON,* M.Sc. Hon. (R.A.U.), J. H. VILJOEN* B.A. (Visitors), N. B. STRYDOM* M.Sc. Ph.D. (Illinois) (Fellow)

SYNOPSIS

Bad eyesight and poor illumination can contribute to the occurrence of accidents in mines. As one part of a study of this problem, surveys of light intensities have been conducted in 19 gold mines. On 17 of the mines the surveys were on one underground level only, whilst in two of the mines more intensive surveys were conducted by measuring light intensities in all areas to determine any inter-mine variations between the levels of illumination.

Readings of light intensity were taken underground at stations, tips, winches, stopes, conveyor belts, waiting places, pump stations, fitters' and boilermakers' workshops, ambulance rooms and in haulages.

It is concluded that the average levels of illumination in South African gold mines are comparable with those reported in the literature for mines elsewhere. Standardisation of lighting conditions underground could eliminate inter- and intra-mine variation in illumination levelswhere they occur. A guide to mine illumination practice would assist such standardisation, and help increase the levels and effectiveness of illumination in mines. Some suggestions are made in this latter connection.

INTRODUCTION

Industry in general and the mining industry in particular is constantly faced with the problem of accidents. Two of the factors contributing to the occurrence of accidents are bad eyesight and poor illumination. To determine eye defects visual acuity tests are required but, unfortunately, visual acuity tests as applied to labourers in industry are not always applicable to the work situation. For instance, the results of vision tests carried out in daylight would be of little use in areas where the light intensity is below 50 lux. In other words, to be meaningful, visual acuity tests on mine labourers should be carried out at the illumination levels existing underground. In the same context, red, yellow and green warning signs would be ineffective if they were illuminated by a light source of only minimum intensity.

Good lighting requires that the needs of safety and welfare be taken into account, as well as that for visual efficiency. Where a task is visually exacting and vigilance is necessary, illumination must be good if the work is to be done efficiently and without strain. Where the task is visually simple, comparable efficiency can be achieved at much lower levels of illumination. According to Bell[1] good lighting is necessary at all underground working places and has three main aims, namely, to:

(*a*) increase productivity,

(*b*) increase safety,

(*c*) create, as far as possible, a pleasant environment.

Only inadequate information on the average light intensity underground in gold mines is available. Kethro,[2] one of the first to measure illumination levels underground in South African mines, obtained illumination values at only one mine for stations, waiting places, etc. Without more extensive information on underground lighting it is impossible to administer meaningful acuity tests or to make recommendations in respect of light intensities for underground use. In this paper an attempt is made to rectify these shortcomings by presenting data on light intensities in different working places underground in mines.

METHOD

The survey was conducted on 19 mines. Of the 19 mines, 17 were surveyed on one underground level only, while the observer was accompanying the mine overseer on his normal inspection rounds. Intensive surveys were made of two of the mines by measuring the light intensities in all shafts to establish any intra- and inter-mine variations. Light intensity readings were taken underground at stations, tips, winches, stopes, conveyor belts, waiting places, pump stations, fitters' and boilermakers' workshops, ambulance rooms and haulages.

In the determination of the light intensities, use was made of a Weston light meter which was cosine and colour-corrected with a sensitive photo-electric cell coupled to a milliammeter. The scale of the meter was calibrated in foot candles or lm/ft^2. Light intensity readings were taken with the photo-electric cell maintained in a horizontal plane while ensuring that no shadows fell onto the cell. The cell was either held at chest height or, where a specific task was being done, the readings were taken at the actual working site. Light intensity recordings at the different working sites were taken as follows:

(*a*) Stations: at the shaft and more or less in the middle of the station floor.

(*b*) Tips: where the Bantu performed their actual work.

(*c*) Winches: where the operator sat, at eye height and also at the controls.

(*d*) Conveyor belts: along the belt, underneath and between lights, as well as at the tip where most of the work was done.

(*e*) Waiting places: where provision was made for the Bantu workers to sit.

(*f*) Pump stations: readings were taken so that an average value could be obtained.

(*g*) Haulages: directly under a light source and also between two adjacent light sources.

*Human Sciences Laboratory, Chamber of Mines of South Africa.

In all instances the type of lighting, for example, fluorescent or incandescent lighting, the number of fittings, their wattage and a general description of the surroundings were recorded.

The level of illumination in stopes required a separate study because the only source of light used there is the miner's cap lamp which is a point light source. The available light in a stope at any time is the light output of the individual cap lamp multiplied by the total number of lamps in that particular area. In this study 20 lamps, 10 lamps from each of two major manufacturers drawn at random from two different mine lamp houses, were used. In order to simplify matters, the lamps from the two manufacturers will be identified as lamps A and lamps B.

The direct light output of each of the 20 lamps was measured at a distance of three inches, while the light output of two lamps of type A and two lamps of type B were also measured at distances of 3 ft, 6 ft, and 20 ft. Finally the light output of all 10 lamps of type A together and all 10 lamps of type B together were measured at distances of 3 ft, 6 ft, and 20 ft.

RESULTS

General Survey

In Table I, in rank order, and Fig. 1 are given the mean light intensities, in both lumens and lux units, of the different working places surveyed and also the frequency distribution of the observations.

The Table shows that there are wide differences in light intensity in various working places, varying from a mean of 82 lux in electrical sub-stations to a mean of 7.5 in haulages, and also a wide spread of observations in each working place. These points are summarised below:—

Work place	*Mean light intensity* (lux units)	*Range of the majority of observations*
Electrical sub-station	82	11 - 53
Conveyor belt	64	1 - 31
Pump station	56	22 - 42
Station (shafts)	48	1 - 42
Workshops	44	1 - 64
First Aid Stations	40	1 - 32
Tips	34	1 - 30
Winches	27	1 - 10
Waiting places	17	1- -20
Haulages	7.5	1 - 10
Stopes	2 - 4	—

Intensive Study

Comparison of the mean light intensities in different working places in two mines, in which intensive studies were made, is given in Fig. 2 and shows that, with the exception of shaft stations and tips, there is no uniformity in underground lighting.

In Fig. 3 a comparison is given of the light intensities in various shafts of the two mines. Striking differences were found between shafts in the same mine.

TABLE I

AVERAGE ILLUMINATION EMITTED BY DIFFERENT SOURCES AND LIGHT INTENSITY FREQUENCIES IN DIFFERENT WORKING PLACES.

Working Place	No. Visited	Total average light intensity for industry lm/ft²	Frequency Distribution of Readings of Light Intensity Measurements in lm/ft² (more than one reading per site)													
			0.0	0.1-0.9	1.0-1.9	2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-10.0	10.1-15.0	15.1-20.0	20.1-30.0	30.1-50.0
Elect. sub-station	11	7.6 (81.8 lux)*			4	2	3	2	1			1	4	1	1	
Conveyor belts	6	5.9 (63.5 lux)		5	7	5	1	3	4	1	1	1	1	1		1
Pump stations	13	5.2 (56.0 lux)		4	2	6	6	3	1		3	2	1	3		
Stations	26	4.5 (48.4 lux)		7	6	6	7	4	5	1	3	1	5	1		
Workshops	21	4.1 (44.1 lux)		6	10	5	8	7	7	1	3	1	1	1	1	
First Aid	7	3.7 (39.8 lux)		3	4	3	2						1	1		
Tips	26	3.2 (34.4 lux)	1	19	10	4	1	3	1		1	3	1		1	
Winches	17	2.5 (26.9 lux)	2	11	3	2	4	1			1	1	2			
Waiting places	13	1.6 (17.2 lux)	1	7	5	3		1			1					
Haulages	17	0.7 (7.5 lux)	2	17	4	1			1							

*(1 lm/ft² = 10.76 lux)

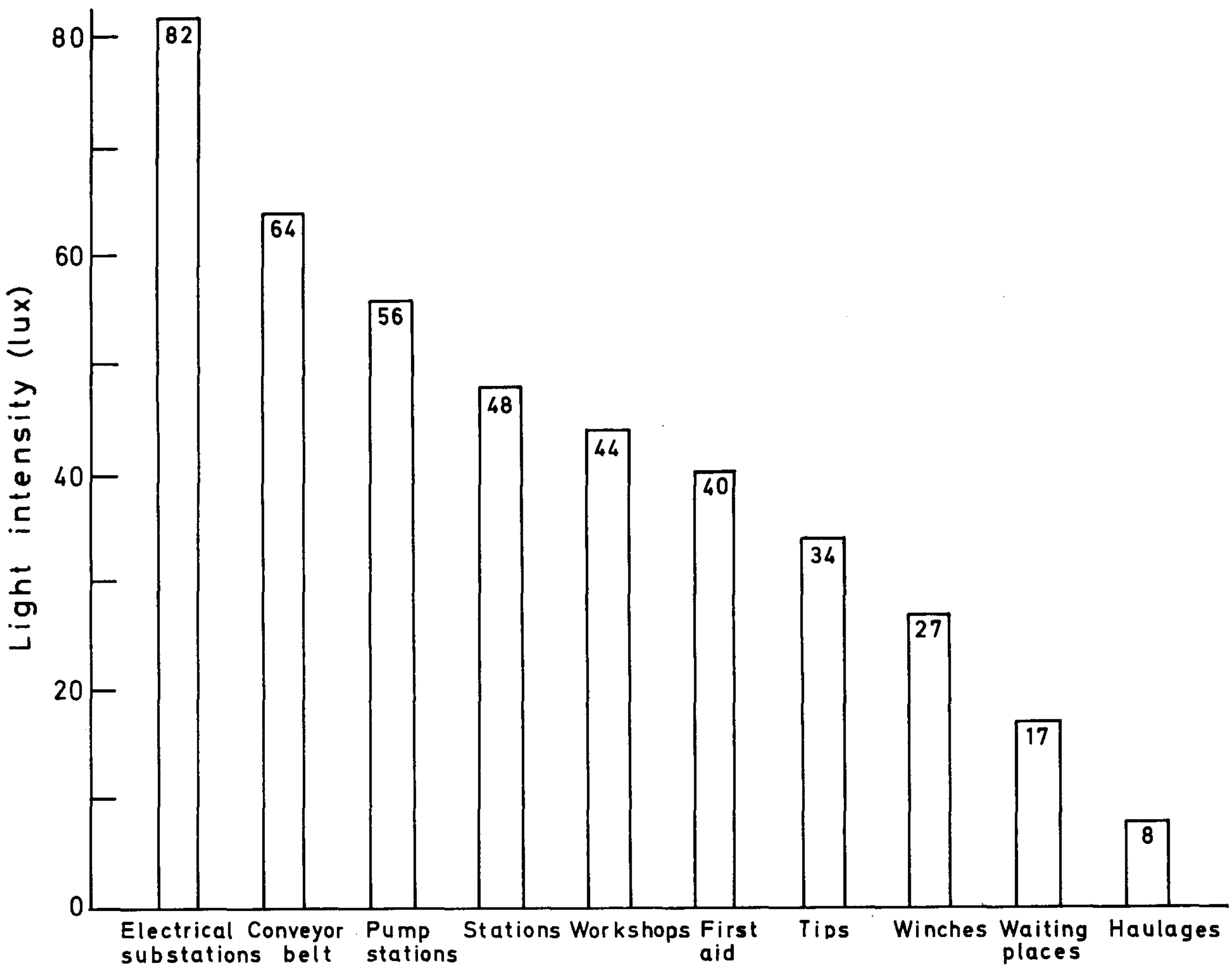

Fig. 1—Mean underground light intensities in different working places in 19 gold mines.

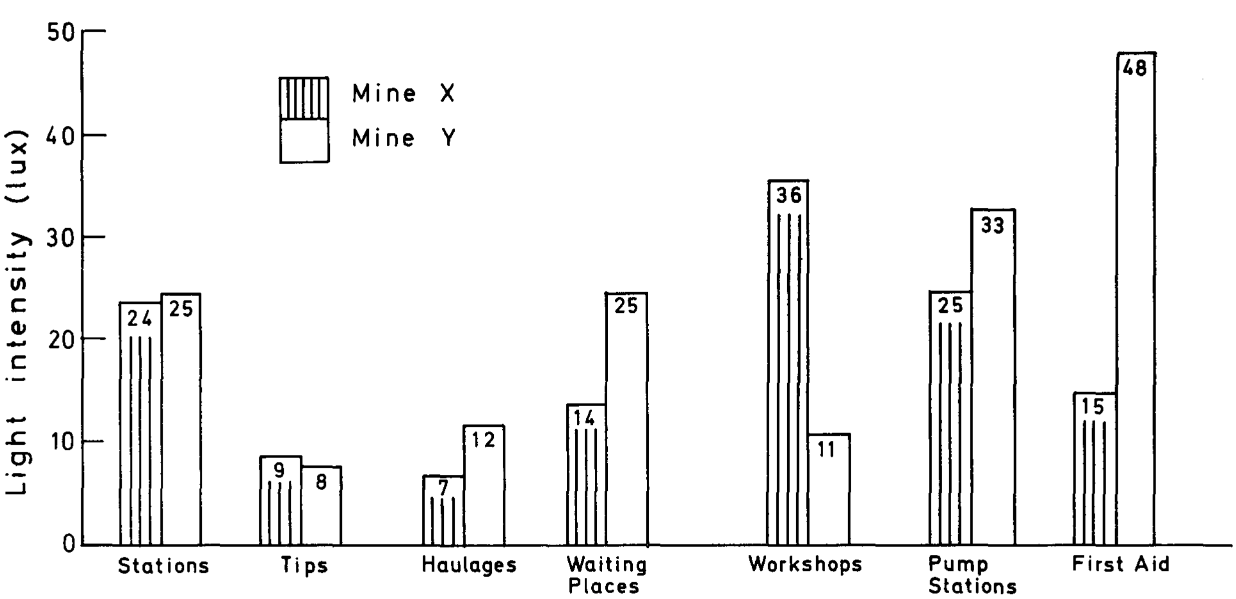

Fig. 2—Mean underground light intensities at different working places in two gold mines.

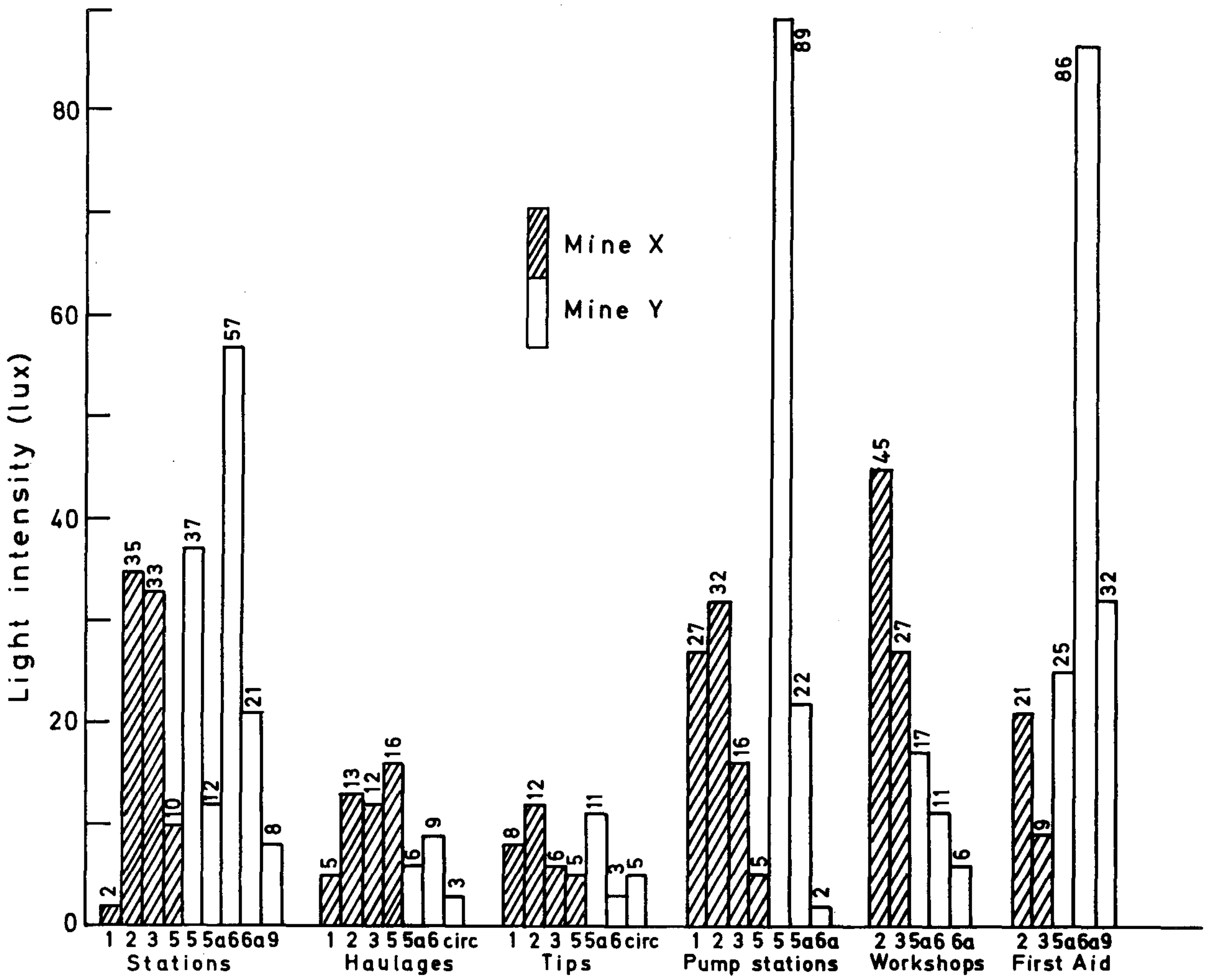

Fig. 3—Mean underground light intensities measured at similar working places in different shafts.

Cap Lamp Study

The results of the study on cap lamps showed that, at a distance of three feet, the light outputs of individual lamps of type A varied from 1 098 lux to 2 755 lux, with an average of 1 915 lux while that of the individual lamps of type B varied from 2 260 lux to 3 465 lux, with an average of 2 722 lux. The light outputs of the two lamps with the lowest and highest outputs at various distances, and the outputs of the two groups of 10 lamps, are given in Table II.

DISCUSSION

The I.E.S. (Illuminating Engineering Society)[3] code for good interior lighting, 1961, recommends a minimum illumination of 161 lux for all working areas and states that 65 lux is virtually the legal minimum standard in areas where people are regularly employed. Bell[4] suggests the following illumination values for coal mines; at floor level, in general working roadways, 12 lux; at floor level in specific areas (i.e. skip loading installations) 65 lux; and at floor level, at the loop junction, 43 lux. Strachan[5] suggested illumination levels at shaft bottoms of 65 lux to 108 lux, for main junction, loading points and stations 43 lux to 65 lux and for other underground roadways 2 lux to 4 lux.

Robert[6] states that a general illumination level of 54 lux is regarded as a desirable minimum standard for pit bottoms and in immediate approaches to the pits. At a main transport station the illumination level is, say, 54 lux and if in the inbye environment the level is 5 lux then to allow for the eye to adapt to dark there must be a decrease at some point from the higher to the lower level with an intermediate illumination level. It must be remembered that the eye responds to differences in accordance with the Weber-Fenchner law; therefore to step down from an average level of 54 lux to one of 5 lux through one intermediate stage, the level of that stage should be the geometrical mean of 54 lux and 5 lux and not the arithmetical mean. The required intermediate illumination level is about 17 lux.

Shirt[7] quotes average illumination levels for different underground areas as used by different countries. In Australia the average underground illumination levels in coal mines are between 215 lux and 22 lux. In France the average level at loading points is 54 lux. In Hungary the illumination level at the pit-bottom on a plane 1 metre above floor level is 65 lux. In mines in Japan the illumination from incandescent lighting is from 22 lux to 43 lux and from fluorescent light from 43 to 70 lux. In Poland incandescent lamps are being superceded by fluorescent lamps underground. This is certainly a commendable approach wherever possible because of the superior light output of fluorescent over incandescent lamps.

TABLE II

A COMPARISON OF TWO TYPES OF CAP LAMPS USED IN THE MINING INDUSTRY

Mine Lamps of Type A

No. of Lamps

	1	2	3	4	5	6	7	8	9	10	AVERAGE
lm/ft²	102.0	256.0	199.0	145.0	227.0	153.0	168.0	188.0	199.0	143.0	178.0
lux	1 097.5	2 754.6	2 141.2	1 560.2	2 442.5	1 646.3	1 807.7	2 022.9	2 141.2	1 538.7	1 915.3

	3 ft	6 ft	20 ft
No. 1	11.4 (122.7)	3.5 (37.7)	0.3 (3.2)
No. 2	20.4 (219.5)	4.1 (44.1)	0.3 (3.2)
All 10	47.0 (505.7)	31.5 (338.9)	2.5 (26.9)

Mine Lamps of Type B

No. of Lamps

	1	2	3	4	5	6	7	8	9	10	AVERAGE
lm/ft²	210.0	322.0	260.0	211.0	228.0	271.0	247.0	238.0	277.0	265.0	253.0
lux	2 259.6	3 464.7	2 797.6	2 270.4	2 453.3	2 916.0	2 657.7	2 560.9	2 980.5	2 851.4	2 722.3

	3 ft	6 ft	20 ft
No. 1	34.0 (365.8)	11.0 (118.4)	1.2 (12.9)
No. 2	55.0 (591.8)	15.3 (164.6)	2.5 (26.9)
All 10	216.0(2 324.2)	62.0 (667.1)	10.0 (107.6)

In Table III[8] are given the average illumination levels at floor level on shaft stations in various countries.

Bell[9] states that, at present, the economic minimum level of illumination is 65 lux in the vicinity of the shafts, 43 lux for junctions and other places where traffic converges or other hazards are present, and 11 lux in normal roadways throughout the mine and especially where travelling ways exist.

From the foregoing papers it is clear that the average illumination levels used by the rest of the mining world is about 54 to 65 lux for stations or areas where men are expected to work, 43 lux at junctions or hazardous areas and 5 to 11 lux for travelling ways such as haulages or waiting places.

The average illumination levels found in South African mines as measured in the present studies are in general agreement with these recommendations. Stations were found to have an average illumination of 48 lux which is very close to the 54 to 65 suggested in the literature. The illumination at workshops, first-aid rooms, tips and winches, is, however, too low and should be increased to the generally recommended level of 50 to 60 lux. This is also supported by Kethro's measurements.

The illumination level in haulages also falls within the recommended 5 to 11 lux. Here, however, attention should be given to junctions and hazardous areas where the illumination should be improved. Certain mining personnel maintain that the absence of illumination in the haulages is better because it permits easier recognition of oncoming trains which have their own light sources. However, contrary to this belief, it must be pointed out that total darkness in the haulages could increase the risk of accidents because the cap lamp illuminates a pin point area only, and any protruding objects or uneven surfaces would not be visible.

Even though the average figures for the South African mining industry as a whole compare favourably with those given in the literature there is room for improvement, particularly as shown by the great inter- and intramine variation (see Fig. 2 and 3 and Table I). It is not uncommon to find two stations, one above the other, one with very good lighting, 108 to 161 lux, and the other with poor lighting (less than 11 lux). It seems that the only way in which this position can be improved is to have a code of practice for the illumination of different working places.

TABLE III

SHAFT STATION LIGHTING DETAILS

Country	Use of Stationmen or Mineral	Transport of Material Trucks or Conveyor	Type of Fitting	Type and Size of Lamps	Mounting of Fittings	Spacing of Fittings	Height of Fittings above floor level	Cleaning Period	Lamp Exchanging Period	Illumination at Floor Level Max/min.	Use of Whitening Agent on Walls or Roof
Belgium	Both	Trucks	F.L.P. Well Glass	Sodium 85 W	Roof	18 m	3.80 m	Every 3 months	After 3 000 hrs	68 lux 21 lux	Both
Canada	Both	Trucks	Non F.L.P.	Tungsten 100/150 W	Roof	5 m	2.17 m	When lamps changed	After Failure	100 lux 50 lux	Both
Czecho-slovakia	Both	Trucks	F.L.P. Well Glass	Tungsten 300/500 W	Roof	Various	4/6 m	When lamps changed	After Failure	65 lux 17.5 lux	Both
Germany	Both	—	F.L.P.	Fluorescent	Roof	4/9 m	2.5/6 m	When lamps changed	After Failure	60 lux 40 lux	Both
Hungary	Both	Trucks	Tungsten F.L.P. Fluorescent	Tungsten 25/100 W Fluorescent	Roof and Wall	5/7 m	3.5/4 m	When lamps changed	After Failure	40 lux 0 lux	Both
Italy	Both	Trucks	F.L.P. Well Glass	Tungsten 40/60 W Fluorescent	Roof	5/10 m	3 m	6 months or when lamps changed	After Failure	20 lux Tungsten 50 lux Fluorescent (average)	Walls
Poland	Both	Trucks	Tungsten F.L.P. Fluorescent Non F.L.P.	Tungsten 150/200 W Fluorescent 3 × 20 W	Roof	4/6 m	2.5/4 m	At specific intervals	After Failure	50 lux 10 lux	Both
Rumania	Both	Trucks	F.L.P.	Tungsten 100 W	Roof	4 m	215/315 m	Every 2 months	After Failure	6 lux 4 lux	Both
Sweden	Both	Both	Non F.L.P. Bare lamp and Reflectors	Fluorescent 2 × 15 W 1 × 40 W	Roof and Wall	2/6 m	2/4 m	Once per month in some instances. When lamps changed in others	After Failure	200 lux 100 lux	Both
United Kingdom	Both	Trucks	F.L.P. If Tungsten Prismatic If Fluorescent, no control	Tungsten 200 W Fluorescent 80 W	Roof	5 m	4 m	When lamps changed	After Failure	60 lux 40 lux	Both
U.S.S.R.	Either or both	—	F.L.P. when necessary	Tungsten 100/200 W Fluorescent	Roof or Roof and Wall	5/12 m depending on width	As great as possible	—	Tungsten After Failure Fluorescent after 70% dim	10 lux 5 lux	Both

A contributory factor to the inter- and intra-individual differences which can easily be corrected is the fact that in the mines dust and dirt are deposited on light sources and these reduce their light output. Kethro increased the illumination of a fluorescent light at an underground mine station from 194 lux to 323 lux by simply cleaning it. In this study 28 incandescent light sources were selected at random and their light outputs measured before and after cleaning. An average increase of 23 per cent in illumination was obtained. The light output of one cleaned fluorescent light increased by 28.6 per cent. Regular maintenance by cleaning gangs is of utmost importance if underground lighting is to remain effective. One of the problems in cleaning incandescent light sources is that if they are not allowed to cool down before being wiped with a damp cloth, they might shatter. It is therefore suggested that a few spare clean globes be given to the cleaner so that he can remove a hot dirty globe and fit a cold clean one in its place. As soon as the removed bulb has cooled sufficiently (after about three to five minutes) it can be cleaned and substituted for a dirty, hot globe.

Another important requirement of good lighting is that installations shall be free of excessive glare caused by the light sources. Glare has been defined by Stanley[10] as "light out of place". It is any brightness within the field of view which causes discomfort, annoyance, interference with vision, or eye fatigue. Precautions to guard against excessive glare should be taken, such as screening of lamps and preventing reflection from glossy surfaces by coating them with a matt finish. Advantage is gained by the use of light surfaces rather than dark surfaces, for instance by white-washing rock walls in haulages and at stations. Frosted or opal electric globes should be used instead of the ordinary clear glass type, because they produce substantially less glare with only a very slight fall in light output.

The problem of correctly grading the lighting to allow adequate time for a man to adapt himself to dark or light, when passing from one area to another, is of great importance. Accidents may result if people leave a well-lit working area and pass immediately into an area where the lighting is inadequate as the time needed for adaptation of the eye to lower levels of illumination may be too long to permit obstacles to be seen sufficiently quickly. A miner on entering a mine is adapted to a very high level of brightness. He is then very rapidly plunged into complete darkness as he descends into the mine as usually no illumination is provided in the cage. When he leaves the cage at stations he is subject to the risk of accidents if entrance areas and particularly steps are poorly lit.

The question of illumination in stopes is a very vexed one. Surveys[11, 12] have shown that the majority of accidents in the mines occur in stopes and it is in stopes that the poorest *general* illumination in the mine occurs; the average level of illumination was between 2-4 lux. This is due to the fact that cap lamps are used in these working places. There are two immediate problems with cap lamps.

One is that very substantial variations were found between the light outputs by fully-charged cap lamps from the same manufacturer (Table II). This is probably due to the fact that the efficiency of the light source depends upon the absorption of light by the reflector and lens glass as well as on the positioning of the bulb. Another factor is the state of charge of the batteries. A striking feature of this study was the superiority of the light output of lamps of type B. The average light output by lamps of type B was 2 722 lux in comparison with 1 915 lux by lamps of type A. It should be pointed out, however, that only a small number of lamps was tested. Although the lamps were drawn at random from two different mine lamp houses no information was available as to the year of manufacture nor the period or conditions under which they were used. A fair comparison would only be possible if all these parameters are catered for.

The other problem is that although the light output of a good lamp is very high (161 to 323 lux at a distance of six feet), it still remains a point light source. According to White,[14] the lack of uniformity in the visual field creates problems due to the fact that the eyes tend to fixate points of intense light. When these points do not coincide with the work under observation, opposing muscles must overcome the tendency of the eyes to turn away from the work towards the light source. This is a frequent cause of discomfort and fatigue.

One of the diseases dreaded by miners in the past was nystagmus, which was caused by inadequate illumination of working places.[13] The introduction of cap lamps effected a considerable improvement and the number of new cases has decreased each year until, at present, no new cases of nystagmus are occurring. However, although cap lamps have effected an improvement in this regard there still remains the problem that the general level of illumination in stopes is too low for efficient and safe work, especially in the general conditions where there are rough surfaces and projections from the footwalls and hangings. The industry should give special and urgent attention to the problems of the proper illumination of stopes, such as flood lighting, as is done in coal mines

There is little doubt that improved illumination underground would have beneficial effects on production and accidents. Shirt[7] states that in the U.S.S.R. it has been observed that, following the introduction of fluorescent lighting on the coal face, the productivity of fillers increased by 3.5 per cent and that the number of accidents fell by 40 per cent. The introduction into mines of projector lighting has brought about an increase in productivity from 7.4 to 10 per cent. It is, however, very difficult to demonstrate the indirect benefits arising from improved lighting, such as improved morale, better supervision, better work motivation and efficiency, and less fatigue.

The following are the general conclusions of this study:

1. Large inter- and intra-mine variations in underground illumination were found. These variations can be eliminated by standardizing lighting conditions underground.
2. By simply cleaning existing underground light sources an average increase of 23 per cent in illumination was obtained. Regular maintenance of all light sources is suggested.
3. The light intensity within a mine should be graded to allow adequate time for the eye to adapt to various light intensities.
4. Cap lamps should be tested photometrically before being put into use and at regular intervals thereafter to ensure a uniform standard of light output being maintained.
5. Glare could be reduced by making use of shielded fittings, frosted globes and by white-washing the rock walls in haulages and stations.
6. More use could be made of fluorescent lighting because of the higher light output of this source.

7. The average levels of illumination in stopes is 2-4 lux, which is inadequate for efficient and safe work; special attention should be given to this problem.

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