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Assessment and Determination of Illumination Needs for Operators of Mobile Surface Mining Equipment

By Alan G. Mayton

UNITED STATES DEPARTMENT OF THE INTERIOR

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

cd/m^2	candela per square meter	in	inch
deg	degree	lx	lux
fc	footcandle	mph	mile per hour
fL	footlambert	s	second
ft	foot	yr	year
h/d	hour per day		

ASSESSMENT AND DETERMINATION OF ILLUMINATION NEEDS FOR OPERATORS OF MOBILE SURFACE MINING EQUIPMENT

By Alan G. Mayton[1]

ABSTRACT

The Bureau of Mines conducted one of the most extensive studies on surface mine illumination to date, to assess the illumination needs of mobile surface mining machinery with respect to the visual tasks required of machinery operators. Field investigations were performed at 22 surface mining operations, coal and metal-nonmetal, within several mining regions of the United States. Visibility and illumination were measured for 159 visual tasks performed by equipment operators on or near 57 surface mining machines, including draglines, shovels, blasthole drills, bulldozers, loaders, haul trucks, graders, scrapers, and several service-type vehicles.

The report shows that illumination and/or visibility could be improved for various visual tasks and makes recommendations for these improvements. Moreover, the report describes the various equipment studied, gives details of the instruments and measuring techniques used, and presents equations to calculate the luminance and illuminance levels suggested for performing mining tasks. Tables are presented that compare values of illumination computed for workers in the 25- and 50-yr age groups. Appendixes to the report includes a glossary of terms, abbreviations, symbols, and calibration and analysis procedures.

[1]Mining engineer, Pittsburgh Research Center, Bureau of Mines, Pittsburgh, PA.

INTRODUCTION

Surface mines, which can cover many square miles of land, use very large, electric- or diesel-powered, mobile construction-type equipment. Most surface mines run their machinery 24 h/d to meet production quotas and to recover costs of capital investments. When persons work on or about equipment of this size and power, safety is obviously a major concern. When work activities take place during nighttime hours, safety practices take on an important dimension--the provision for proper and effective illumination.

Since the passage of the Coal Mine Health and Safety Act of 1969, the Bureau of Mines has played a major role in illumination research and in the development of illumination criteria and technology to provide adequate lighting for workers in U.S. mining operations. This has been accomplished most notably in underground coal mining, and to a degree, in surface mining.

In 1977, the Mining Enforcement and Safety Administration (MESA) under the Department of the Interior (now the Mine Safety and Health Administration (MSHA) under the Department of Labor) proposed mandatory safety standards of illumination for surface coal mines and surface work areas of underground coal mines (1).[2] These standards, however, were never approved. In 1981, the International Commission on Illumination (CIE) began to focus attention on illumination standards for surface mining by establishing a program to develop recommendations for opencast (surface mine) lighting. Concurrent with its involvement with the CIE and in view of the lack of approved lighting standards, the Bureau initiated a program to study illumination on mobile surface mining equipment from the viewpoint of the equipment operators. The objective of the program was to assess the illumination needs of various surface mining equipment on the basis of the visibility required by workers in performing the necessary visual tasks associated with their jobs. Overall, the intent of the study was to provide useful data and information for MSHA and the CIE to use in establishing lighting standards and recommending lighting practices for surface mines.

ACKNOWLEDGMENTS

The author thanks C. L. Crouch, president of CLC Associates, Floral Park, NY, and Port Charlotte, FL, for his assistance with the collection and analysis of the data. The author also thanks H. R. Blackwell, president of Visioneering Laboratories, Sarasota, FL, and Frankfurt, MI, for his cooperation and assistance with the visual task evaluator (VTE) instrumentation.

DESCRIPTION AND PROCEDURES

The study was conducted using a VTE (a visibility meter, described in detail later) according to the methods and practices recommended by the CIE and the Illuminating Engineering Society of North America (IES). The main program effort involved the collection of visibility and illumination data through on-site visits to various surface mines and quarries in several mining regions of the United States. Field investigations were conducted at 22 different surface mining operations in Michigan, Indiana, Alabama, Florida, Ohio, Massachusetts, New Hampshire, and New York. Useful data were obtained from 12 of them: 5 metal and nonmetal (M-NM) mines and quarries and 7 coal mines. The M-NM operations included two iron ore mines and three limestone

[2]Underlined numbers in parentheses refer to items in the list of references preceding the appendixes.

quarries.[3] The visual tasks of equipment operators were identified on or about 57 surface mining machines, including quarry equipment. The equipment included draglines, shovels, blasthole drills, bulldozers, loaders, haul trucks, graders, scrapers, lubrication trucks, fuel trucks, and a water truck. Visibility was measured for 159 tasks using the Blackwell model 5 VTE.[4] The existing illumination was determined using the reflectance standard RS-1 (a barium sulfate plaque with a nominal reflectance of 98%) and the Minolta 1° luminance meter.

FIELD MEASUREMENTS

After a visual task of a particular equipment operator was identified, the VTE (fig. 1) was set up in the location from which the operator would normally view the critical detail of the task. The approximate angular position of the VTE and the approximate distance from the outer lens of the VTE to the object or surface of interest were estimated or measured and recorded. The proper outer lens unit (fig. 2) was selected based on the measured (or estimated) distance and attached to the front of the VTE. Then, no fewer than five readings were obtained while looking through the VTE and turning the contrast control dial. After the VTE readings were taken, the luminances of the target (critical detail of the task) and its background were measured with the Minolta meter. The illuminance or illumination of the task was determined by measuring the luminance of the RS-1 plaque (placed on or directly above the target) with the Minolta meter (fig. 3). In addition, Munsell charts were used where needed to determine the reflectance of surfaces of interest (fig. 4). Slide photographs were also taken of the equipment and the detail of each task.

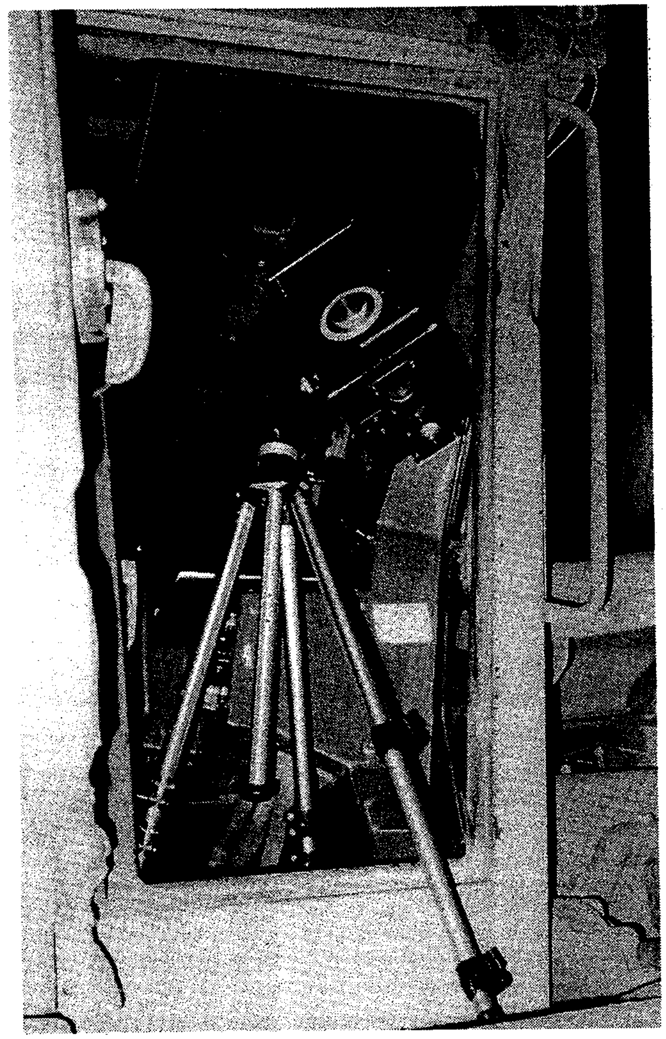

FIGURE 1.—Blackwell model 5, serial No. 2, visual task evaluator (VTE).

VTE DESCRIPTION AND PRINCIPLE OF OPERATION

The Blackwell model 5 VTE is the latest in a series of visibility meters developed by H. Richard Blackwell (2) of Visioneering Laboratories. The main advantage of the new meter is that it uses light from the task environment rather than an internal, diffuse, incandescent

[3]Ten other M-NM operations were vissited. However, the visibility and illumination data from two granite quarries and two limestone quarries are not included because the VTE was later found to be out of calibration. Also, it was not possible to obtain visibility measures at five phosphate mines and one other limestone quarry.

[4]Reference to specific products does not imply endorsement by the Bureau of Mines.

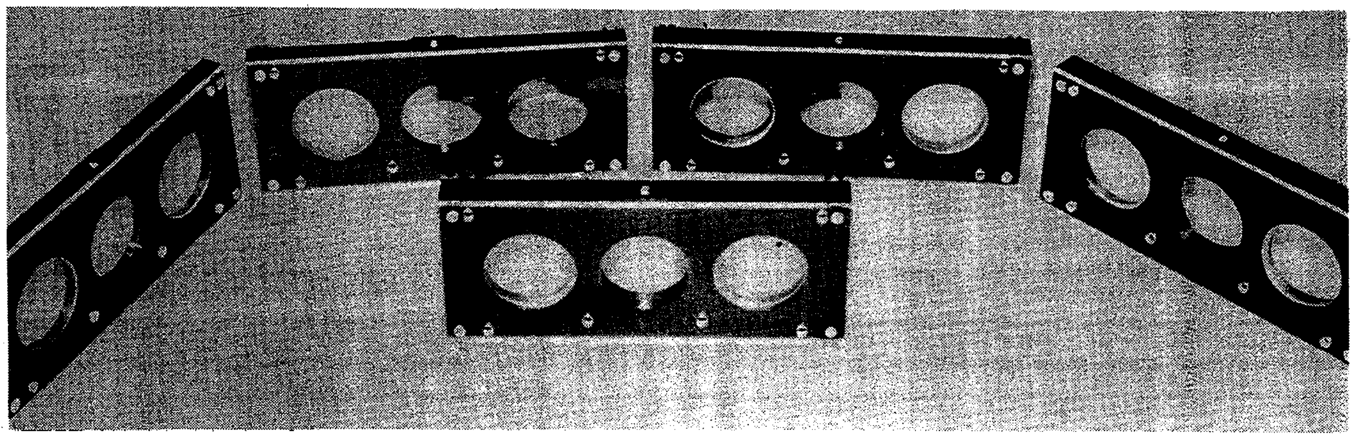

FIGURE 2.—Outer rectangular lens units of VTE.

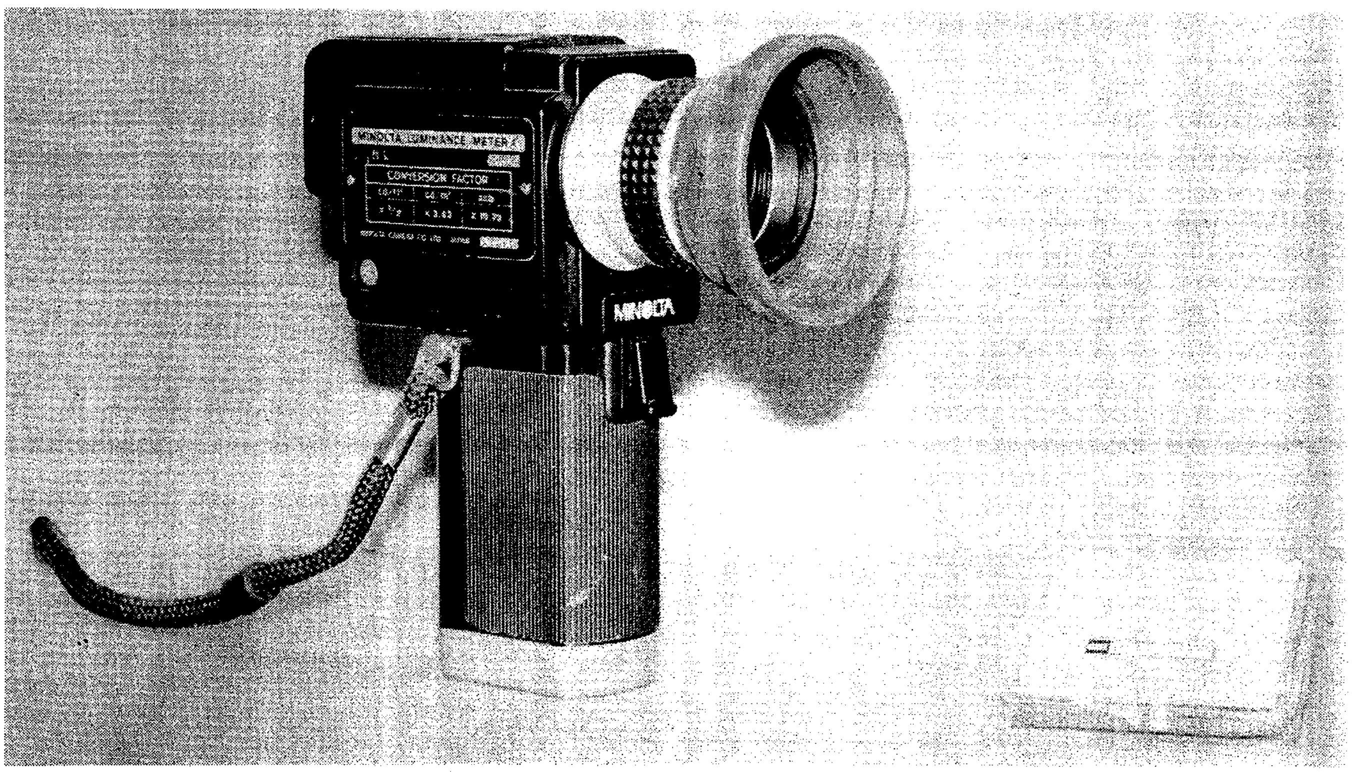

FIGURE 3.—Minolta 1° luminance meter and RS-1 reflectance standard.

source. This makes the VTE very flexible for use in the surface mining environment (3).

The VTE operates by allowing the user to vary the visual contrast of objects seen through the instrument by fading out the luminance of a scene while at the same time introducing a uniform veiling luminance, or "optical fog." The point at which critical detail of the task can be seen just barely through the interven-ing optical fog is called threshold. The proportion of the original contrast pass-ing through the instrument's optics is called the contrast transmittance (CT) of the instrument, which ranges from almost 100% to almost zero as the background lu-minance remains nearly constant (4).

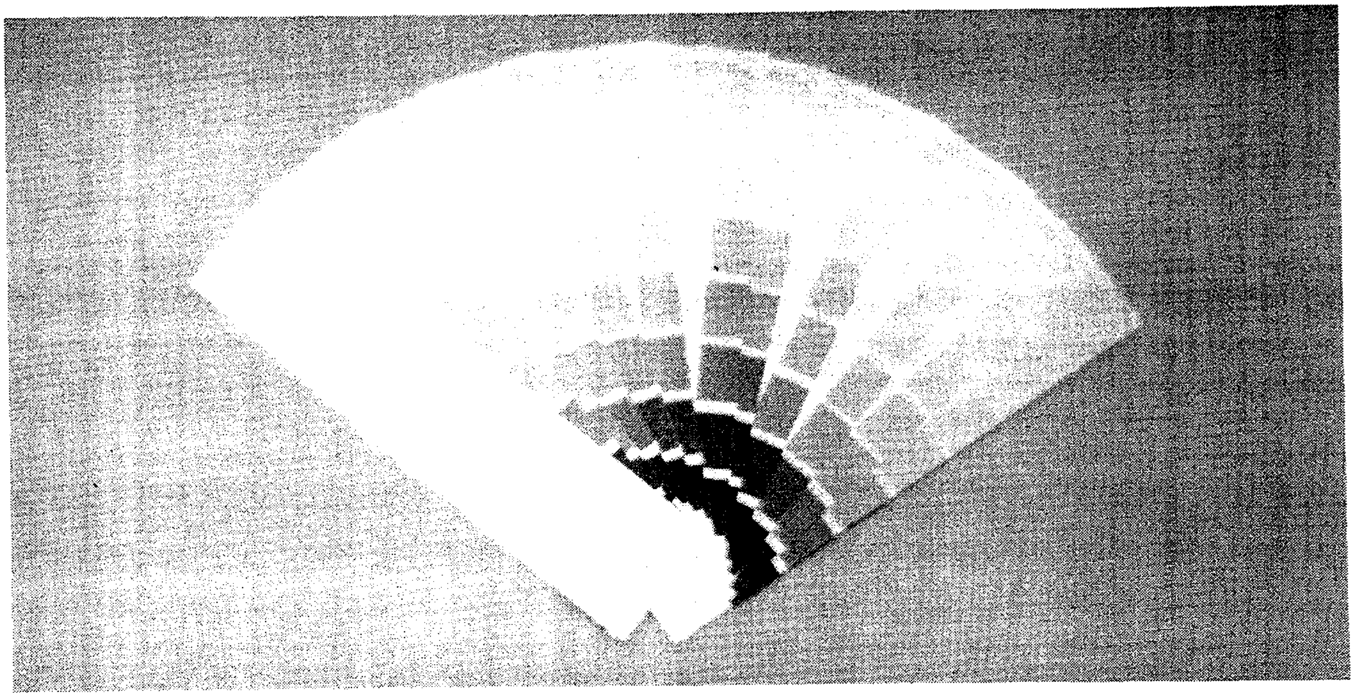

FIGURE 4.—Munsell charts, multicolored chips for judging reflectance.

A measure of how easy or how well a given target can be seen is expressed in the amount of reduction in task contrast that is needed to bring the detail to threshold. If, for example, a given target object reaches visibility threshold at a value of CT equal to 0.10, the target is inherently 10 times above its threshold value. The target is said to have a relative visibility level (VL) of 10. Thus, a measure of relative visibility for objects is determined mathematically by taking the reciprocal of the contrast transmittance; namely, VL = 1/CT. Consequently, scenes that are highly visible will require more contrast reduction (optical fog) to reach visibility threshold, while those that are moderately visible will require less (4-5).

CIE-IES METHOD

The use of the VTE to obtain visibility measurements is based on the CIE-IES method, which compares an actual, real-world visual task with a standard visibility reference task. The visibility reference task consists of an observer viewing (through the VTE) a luminous disk whose diameter subtends 4' of arc at the observer's eyes when it is presented in a series of 0.2-s exposures on a task background with uniform luminance. In turn, the visibility reference task is the basis for the visibility reference function, which represents visibility threshold values obtained by a 20- to 30-yr-old reference observer (6). A detailed explanation of this method is contained in CIE Report 19/2 (7). Further, measuring task visibility with the VTE requires that the VTE user go through a specific calibration procedure. This procedure, with the procedure for analyzing the field data, is included in appendix B at the end of this report.

DISCUSSION AND RESULTS

This section includes a brief description of the different equipment studied, with corresponding tables of illumination data based on measurements of task visibility for equipment operators. The data presented should not be construed as absolute, but should be used as a general guide to help in better understanding the illumination needs of machinery and vehicle operators at surface mines. Also, note the following regarding data in the tables:

Values appearing under the column headings "Computed luminance" and "Computed illuminance" were calculated for the median age in each group, that is, the average 25- and 50-yr-olds of the normal population.

Computed values of luminance and illuminance were rounded off for consistency after the calculations were made.

Variations in luminances and illuminances for similar tasks and equipment are largely the result of the wide differences in the conditions under which field measurements were actually taken.

In general, high contrast between the task target or critical detail and its background will result in good visibility and relatively lower illuminance levels, while low contrast will result in poorer visibility and relatively higher levels of illuminance.

The footnote "Supplemental lighting" on some of the tables refers to illumination added to the scene for certain visual tasks (generally from the direction of normal or existing lighting) to increase the transmittance through the VTE.

SURFACE COAL MINES

Draglines

Draglines are generally very large, mobile, electric-powered excavating machines used to remove and transport overburden (the earth and rock overlying a coalbed) while operating from the top edge of a nearly vertical pit. Those working on or near a dragline include an operator, an oiler, and a groundman who usually operates a track- or wheel-type bulldozer to maintain a relatively uniform ground surface around the dragline and handles the trailing cable for relocation purposes. For obvious safety reasons, good visibility is a necessary concern for tasks on and around the machine. Accordingly, the dragline operator must be able to see the following: the bottom of the pit at the greatest reach and digging depth of the machine, for positioning of the bucket; the point at which the overburden meets the coal, to remove only overburden; the top of the spoil pile or waste dump when disposing of overburden; and on the hoist rope, the bucket-chain assembly including the dump block, to prevent lifting the dump block into the point sheave located at the end of the boom. Other tasks for workers include approaching, boarding, and exiting the machine, routine maintenance, and inspection. A final task involves handling of the trailing cable during relocation maneuvers.[5]

The three draglines observed during field investigations displayed illumination systems consisting of mercury vapor luminaires and some high-pressure sodium vapor luminaires; these were mounted on the boom and around the top edge of the machinery house. Incandescent fixtures were generally located near doorways, walkways, stairways, and ladders, and beneath the mainframe of the machine. Figure 5 shows an illuminated dragline operating at night. Table 1 shows tasks for which visibility was measured, along with the existing and computed illumination and task viewing distances.

In addition to the data in table 1, more comprehensive data on the illumination needs for tasks on draglines can be found in a report by Crouch and Vincent.[6]

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[5]Some information contained in this paragraph was obtained from a "rough" draft report of the CIE Subcommittee SC-4.10B, entitled "Recommended Practices For Open Cast Mine Lighting," and completed on Jan. 25, 1983. This report is yet to be published in its entirety and final form.

[6]This report documents work performed for the Mine Safety Appliance Co. under Bureau contract H03874024. A copy of the report is available upon request from A. G. Mayton, BuMines, Pittsburgh, PA.

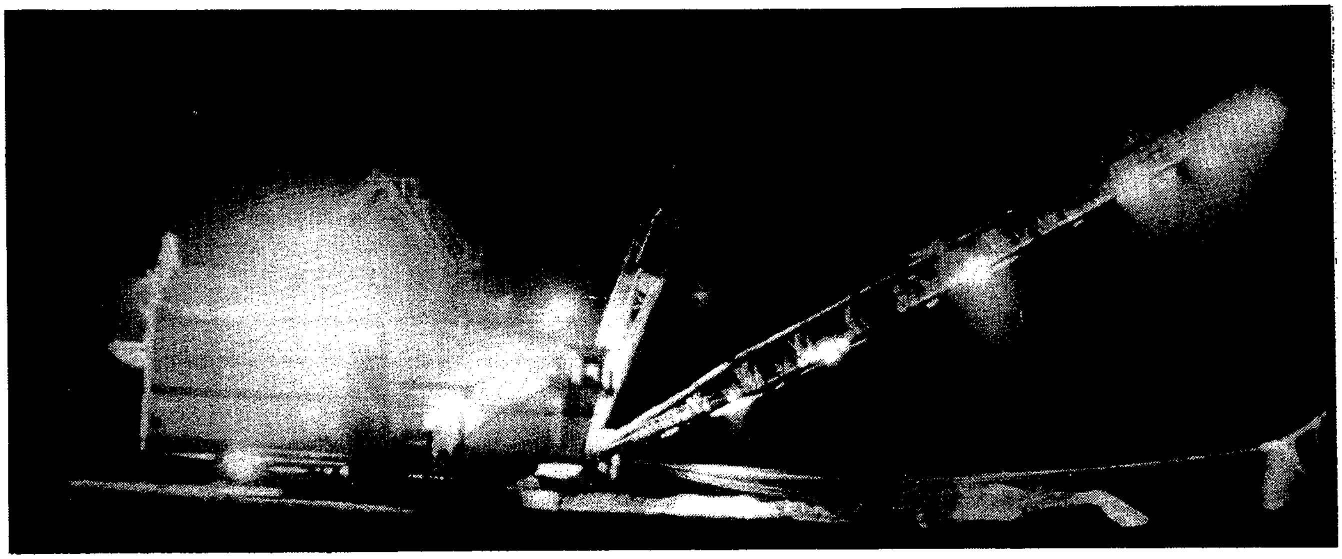

FIGURE 5.—Typical lighting on dragline operating during nighttime hours.

TABLE 1. - Illumination values resulting from task visibility measurements for coal mine draglines

	Existing illuminance, fc	Viewing distance, ft	Computed luminance, fL[1,2]		Reflectance, %	Computed illuminance, fc[1,3]	
			20- to 30-yr-olds	40- to 60-yr-olds		20- to 30-yr-olds	40- to 60-yr-olds
DRAGLINE 1							
Seen from operator's cab: Tooth of bucket resting on ground......	5.11	100	0.058	0.095	9.00	3.10	5.13
DRAGLINE 2							
Seen from operator's cab:							
Top of spoil pile.....	[4]2.40	150	0.036	0.058	2.08	1.74	2.80
Lower edge of bucket on slope of pit......	[4]1.38	105	.371	.743	47.10	.79	1.58
Coal with respect to overburden...........	[4]1.34	150	1.18	2.99	14.18	8.34	21.11
Dump block on hoist rope.................	[4]2.10	150	.039	.063	2.86	1.36	2.19
Seen from ground level at rear of machine: Power cable...........	1.31	3.7	2.22	6.86	9.92	22.40	69.17
DRAGLINE 3							
Seen from operator's cab:							
Control panel button..	9.24	1.8	0.037	0.060	34.52	0.11	0.17
Tooth of bucket resting on ground.......	1.27	241	1.121	2.193	18.90	5.94	11.61
Seen from landing: Edge of landing to stairs...	3.48	4.7	.014	.022	3.45	.41	.61

[1]Calculated for median age in each group.
[2]To convert to candelas per square meter, multiply by 3.426.
[3]To convert to lux, multiply by 10.76.
[4]Extrapolated from other measurements.

Stripping and Loading Shovels

The lighting of both stripping and loading shovels was observed and studied, although task visibility measurements were obtained only for loading shovels. Personnel and visibility requirements are generally the same as those for draglines.

Stripping shovels (fig. 6) work in the pit on top of the coalbed and move along the pit by crawler-type conveyance. Like draglines, they remove a highwall of overburden (up to 100 ft or more) and deposit it on a spoil pile at a distance of the boom's length away. The visibility requirements of the shovel operator and the groundman differ from those of workers on the dragline in that a dominant safety concern is the highwall, which must be monitored continually for dangers due to material falling or rolling down the face of the highwall.

Loading shovels (fig. 7) operate on the bottom of a bench of broken overburden or coal. Bench heights typically range from 15 to 40 ft. The operating characteristics of this type of shovel are the same as those of the stripping shovel, except that the stripping shovel transports the overburden to a spoil pile, while the loading shovel loads overburden or coal into trucks that transport it to a designated dump area or hopper.

Visual tasks were identified and visibility was measured for five loading shovels. Illumination of these shovels, like that of the draglines, was provided by a combination of primarily mercury vapor luminaires with high-pressure sodium and incandescent luminaires. Visual tasks for these machines, with computed values of illumination, are shown in table 2. Additional information on the illumination needs for tasks on electric-powered shovels can also be found in Crouch and Vincent.[7]

[7]See footnote 6.

FIGURE 6.—Stripping shovel with typical lighting system.

TABLE 2. - Illumination values resulting from task visibility measurements for coal mine shovels

	Existing illuminance, fc	Viewing distance, ft	Computed luminance, fL[1,2]		Reflectance, %	Computed illuminance, fc[1,3]	
			20- to 30-yr-olds	40- to 60-yr-olds		20- to 30-yr-olds	40- to 60-yr-olds
SHOVEL 1							
Seen from operator's cab: Rear edge of dipper resting on ground..............	6.84	28	0.381	0.765	16.52	2.31	4.63
SHOVEL 2							
Seen from operator's cab:							
Rear edge of bulldozer..........	1.41	50	0.038	0.061	4.26	0.89	1.43
Rock on slope of bench highwall.....	.70	25	.251	.478	10.00	2.52	4.78
Rear edge of dipper resting on ground..	2.00	24.6	.080	.139	10.00	.80	1.39
SHOVEL 3							
Seen from operator's cab:							
Top rear edge of loaded dipper......	[4]1.40	30	0.240	0.453	10.00	2.40	4.53
Top edge of empty truck bed..........	[4]1.20	20	.062	.103	10.00	.62	1.03
Top edge of truck bed loaded.........	[4]1.30	25	.513	1.08	34.62	1.48	3.12
Height of load in truck..............	[4]1.70	30	.045	.074	1.76	2.58	4.20
Seen from ground level at rear of machine: Power cable..........	.23	3.5	.020	.031	17.39	.12	.63
SHOVEL 4							
Seen from operator's cab: Top rear edge of loaded dipper.....	[4]12.60	25	1.30	3.39	10.00	13.06	33.91
SHOVEL 5							
Seen from ground level at rear of machine:							
Bottom rung of boarding ladder....	2.09	2.3	0.140	0.248	12.92	1.08	1.92
5th rung of boarding ladder used as handhold...........	2.83	1.3	.003	.005	.71	.46	.66

[1]Calculated for median age in each group.
[2]To convert to candelas per square meter, multiply by 3.426.
[3]To convert to lux, multiply by 10.76.
[4]Extrapolated from other measurements.

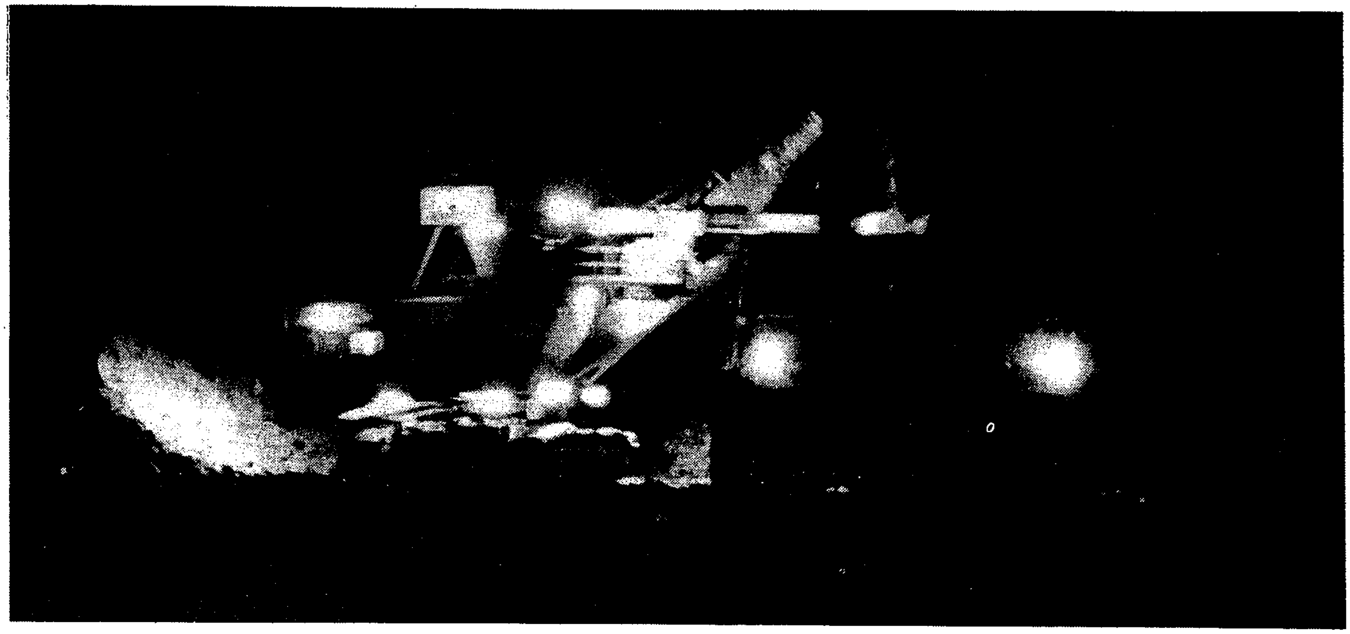

FIGURE 7.—Typical illumination on loading shovel.

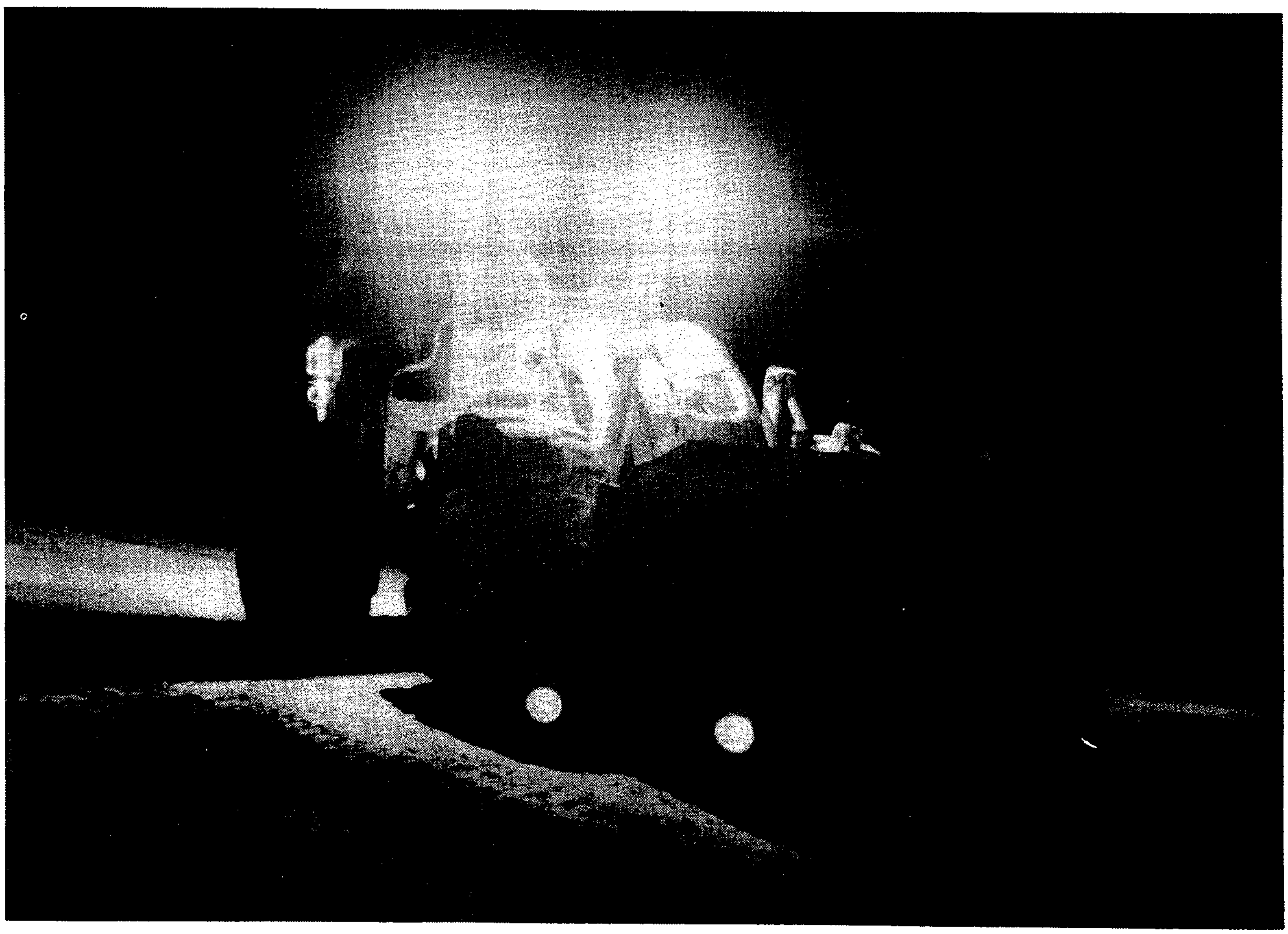

FIGURE 8.—Typical lighting system on loader.

TABLE 3. - Illumination values resulting from task visibility measurements for coal mine loaders

	Existing illuminance, fc	Viewing distance, ft	Computed luminance, fL[1,2]		Reflectance, %	Computed illuminance, fc[1,3]	
			20- to 30-yr-olds	40- to 60-yr-olds		20- to 30-yr-olds	40- to 60-yr-olds
LOADER 1							
Seen from ground level at boarding ladder:							
Bottom step.........	[4]0.78	2.3	0.017	0.026	1.28	1.33	2.06
Handrail............	[4].02	1.4	.016	.024	50.00	.03	.05
Seen from plate-metal landing outside operator's cab:							
Handrail............	1.01	1.4	.017	.026	1.98	.86	1.33
Edge of landing to descend ladder.....	.39	3.6	.068	.114	10.26	.66	1.11
Seen from operator's cab: Height of load in bucket............	.37	15	.031	.050	10.81	.29	.46
LOADER 2							
Seen from operator's cab: Left end of bucket...............	2.65	15	0.028	0.046	1.89	1.51	2.41
LOADER 3							
Seen from operator's cab: Top rear edge of loaded bucket.....	8.78	13	0.162	0.294	17.08	0.95	1.72

[1]Calculated for median age in each group.
[2]To convert to candelas per square meter, multiply by 3.426.
[3]To convert to lux, multiply by 10.76.
[4]Supplemental lighting required to make measurements.

Loaders

A wheel-tractor loader is a very common machine around a surface mining pit. It can be used in a number of ways at a mining operation, but its most important function is to remove overburden or coal and load it into trucks or railroad cars for transport to a designated dump area.

Loader operators must have good visibility to board and exit the equipment via boarding ladders and cab decks or landings. The operators must be able to see the immediate areas adjacent to either end of the bucket, determine when the bucket is full, detect any loose or falling material when near the highwall, determine the position of the truck or railroad car to be loaded with respect to the loader bucket, and see other moving vehicles and hazards when traveling from one location to another within the mine.

Illumination systems on loaders usually consist of regular incandescent or, in some cases, quartz halogen luminaires. Figure 8 shows the lighting system on a typical loader. Table 3 shows existing and computed illumination values for various tasks of loader operators.

Haul Trucks

There are basically two types of haulage trucks used at surface coal mines:

the rear dump, used primarily for transporting overburden, and the center (bottom) dump, used for transporting coal. Illumination of haul trucks consists typically of high- and low-beam headlights and a set of rear-mounted backup lights (on rear dumps only). In some instances, mine operators have mounted an additional floodlight behind the cab of rear-dump trucks for dumping purposes. The visibility required by truck drivers includes the following: seeing the ladders and handrails when boarding and exiting the truck, viewing the area near the shovel or loader at a loading site, viewing the berm or edge of the dump and general area of the dumping site, and readily detecting hazards and other moving equipment on haulage roads when driving from place to place within the mine. Driver visibility was measured for various tasks on five haul trucks. These tasks are shown in table 4 with the existing and computed levels of illumination. Figure 9 shows a typical rear-dump haul truck at a dump site.

Blasthole Drills

Rotary blasthole drills are an important facet of the overburden removal process. Drills are used to bore vertical or angled holes into the overburden. The holes are then filled with explosives and detonated to break up the overburden into fragments that can easily be removed by the excavating equipment. The illumination of drills includes mercury vapor luminaires that are mounted on the top of the operator's cab to illuminate the mast and the drill table or deck through which the drill pipe passes down to the hole. Some drills are also equipped with high-pressure sodium vapor luminaires at the rear and sides of the machines and incandescent fixtures to illuminate doorways to the house, the main walkway, and the boarding stairs or ladders. Figure 10 shows the typical illumination on a drill.

In most cases, two people work on a drill, an operator and an oiler. The visibility required for these workers includes the ability to see the area

FIGURE 9.—Haul truck dumping load at waste dump.

TABLE 4. - Illumination values resulting from task visibility measurements for coal mine haul trucks

	Existing illuminance, fc	Viewing distance, ft	Computed luminance, fL[1,2]		Reflectance, %	Computed illuminance, fc[1,3]	
			20- to 30-yr-olds	40- to 60-yr-olds		20- to 30-yr-olds	40- to 60-yr-olds
TRUCK 1							
Seen from driver's cab:							
Edge of ditch.......	0.50	130	0.107	0.186	14.81	0.72	1.25
Pile of debris in front of truck.....	.54	55	.018	.029	1.85	1.00	1.55
Seen from ground level at boarding ladder:							
Bottom step.........	[4]1.21	2.2	.018	.028	1.65	1.10	1.71
Hand bar...........	[4].61	1.3	.043	.070	8.20	.53	.85
TRUCK 2							
Seen from driver's cab: Left curb at dump hopper..........	1.02	35	0.620	1.37	6.86	9.04	19.97
TRUCK 3							
Seen from driver's cab:							
Edge of berm at waste dump[5]........	0.91	32.5	0.025	0.041	1.10	2.27	3.71
Body-down indicator.	[4].31	3	.069	.115	6.45	1.08	1.78
TRUCK 4							
Landing at head of boarding ladder:							
Handrail of landing.	0.10	1.8	0.022	0.035	20.00	0.11	0.18
Edge of landing (descending).......	.54	3.6	.016	.026	1.80	.89	1.45
TRUCK 5							
Seen from driver's cab:[5]							
Tire track at loading shovel[6]........	3.15	99.3	0.432	0.886	8.89	4.86	9.97
Sloped waste pile at base of bench highwall[6]..........	1.48	138	.198	.367	1.35	14.67	27.18
Rear (shadowed) edge of loading shovel[6].	1.90	99.3	.781	1.78	10.00	7.81	17.80

[1]Calculated for median age in each group.
[2]To convert to candelas per square meter, multiply by 3.426.
[3]To convert to lux, multiply by 10.76.
[4]Supplemental lighting required to make measurements.
[5]Left side-view mirror used.
[6]Positioning and/or maneuvering mark.

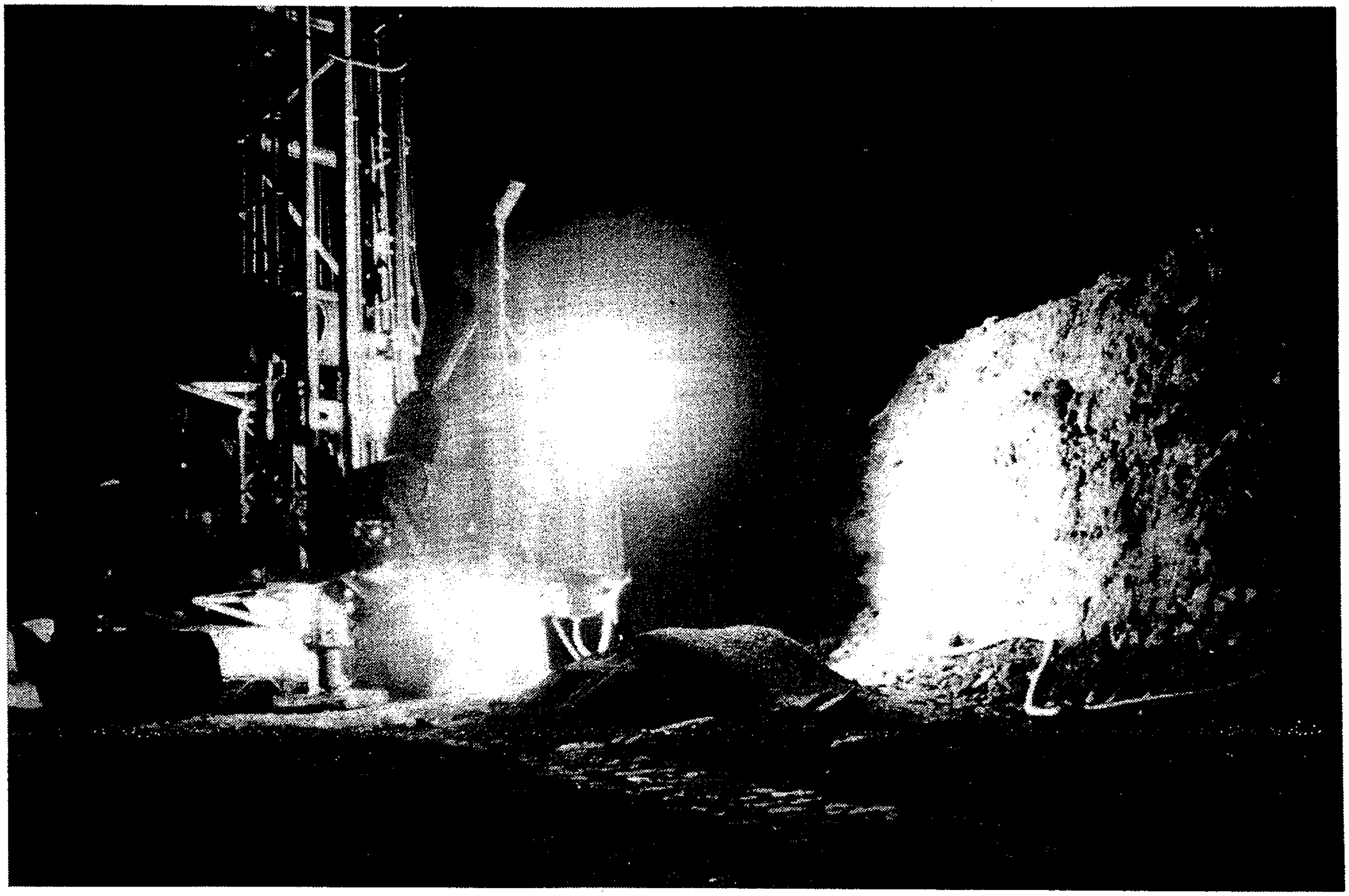

FIGURE 10.—Typical illumination on blasthole drill.

around the drill for different operating maneuvers; walkways, stairs, and ladders for boarding and exiting; and areas immediately adjacent to the operator's and rear sides of the machine to relocate the machine for drilling the next hole. The visibility for various tasks was measured on six blasthole drills; the tasks are shown in table 5 with corresponding illumination levels.

Explosives Trucks

Explosives trucks (figs. 11-12) are used for transporting a bulk explosive mixture or packaged explosives to the location of previously drilled blastholes. Here the driver of the truck loads the blastholes with the explosives and prepares the holes for firing during the next day shift. General visibility requirements include being able to see the general area around the drilled holes, steps and handles for entering or exiting the truck, and hazards or other vehicles while traveling from one location to another in the mine. Specific tasks and corresponding light levels for two explosives trucks are shown in table 6.

Scrapers

Wheel-tractor scrapers are another type of excavating equipment used in surface coal mines. They are used primarily for removing and transporting topsoil or very shallow overburden. Illumination, like that on haulage trucks, is primarily accomplished with headlights that have the high- and low-beam feature. If the machine design permits, mine operators will sometimes add incandescent floodlights to better illuminate the area to the front of a scraper. One other incandescent luminaire is mounted on the rear of the driver's cab to provide illumination for the pan. Figure 13 shows a typical scraper with incandescent lighting.

TABLE 5. - Illumination values resulting from task visibility measurements for coal mine blasthole drills

	Existing illuminance, fc	Viewing distance, ft	Computed luminance, fL[1,2] 20- to 30-yr-olds	Computed luminance, fL[1,2] 40- to 60-yr-olds	Reflectance, %	Computed illuminance, fc[1,3] 20- to 30-yr-olds	Computed illuminance, fc[1,3] 40- to 60-yr-olds
DRILL 1							
Seen from operator's cab:							
Shovel (marker) to align machine for drilling next hole	27.24	60	0.226	0.423	16.52	1.37	2.56
Stem lock against drill pipe	15.10	8	.128	.227	4.44	2.89	5.11
Paint mark on hoist chain	16.53	12	.081	.137	15.12	.54	.91
DRILL 2							
Seen from landing at head of boarding ladder: Edge of landing to descend stairs	2.40	3.7	0.063	0.106	4.17	1.52	2.55
DRILL 3							
Seen in operator's cab: Pointer of pressure gauge	[4]1.51	1.5	0.012	0.018	56.95	0.02	0.03
DRILL 4							
Seen from operator's cab:							
Edge of box (marker) to align machine for drilling next hole	1.43	21	0.568	1.22	6.99	8.12	17.45
Edge of deck bushing against drill pipe	9.18	4.5	.533	1.13	5.45	9.78	20.71
Rope with weighted end for spacing holes	[4]23.30	20	.336	.663	4.25	7.91	15.61
Seen from ground level at operator's cab: Boarding step	2.16	4.5	.028	.045	4.63	.60	.96
DRILL 5							
Seen from operator's cab:							
Edge of deck bushing without drill pipe	2.14	6	0.147	0.262	2.34	6.27	11.21
Edge of pipe rack against drill pipe	4.43	6	.091	.156	10.38	.88	1.50
Seen from ground level at boarding stairs:							
Bottom step	4.50	2.1	.032	.051	8.22	.38	.62
Handrail	1.31	1.8	.095	.163	8.40	1.13	1.94
DRILL 6							
Seen from operator's cab:							
Edge of deck bushing against drill pipe	1.48	5	0.304	0.588	25.00	1.22	2.35
Mark on hoist cable	.93	4.3	.029	.041	13.98	.65	1.00
Drop pin in drill pipe carousel	55	6	.790	1.81	21.82	3.62	8.30
Pointer of pressure gauge	6	1.4	.616	1.35	62.17	.99	2.17
Small hole in deck	2.85	4	.458	.948	32.28	1.42	2.94

[1]Calculated for median age in each group.
[2]To convert to candelas per square meter, multiply by 3.426.
[3]To convert to lux, multiply by 10.76.
[4]Supplemental lighting required to make measurements.

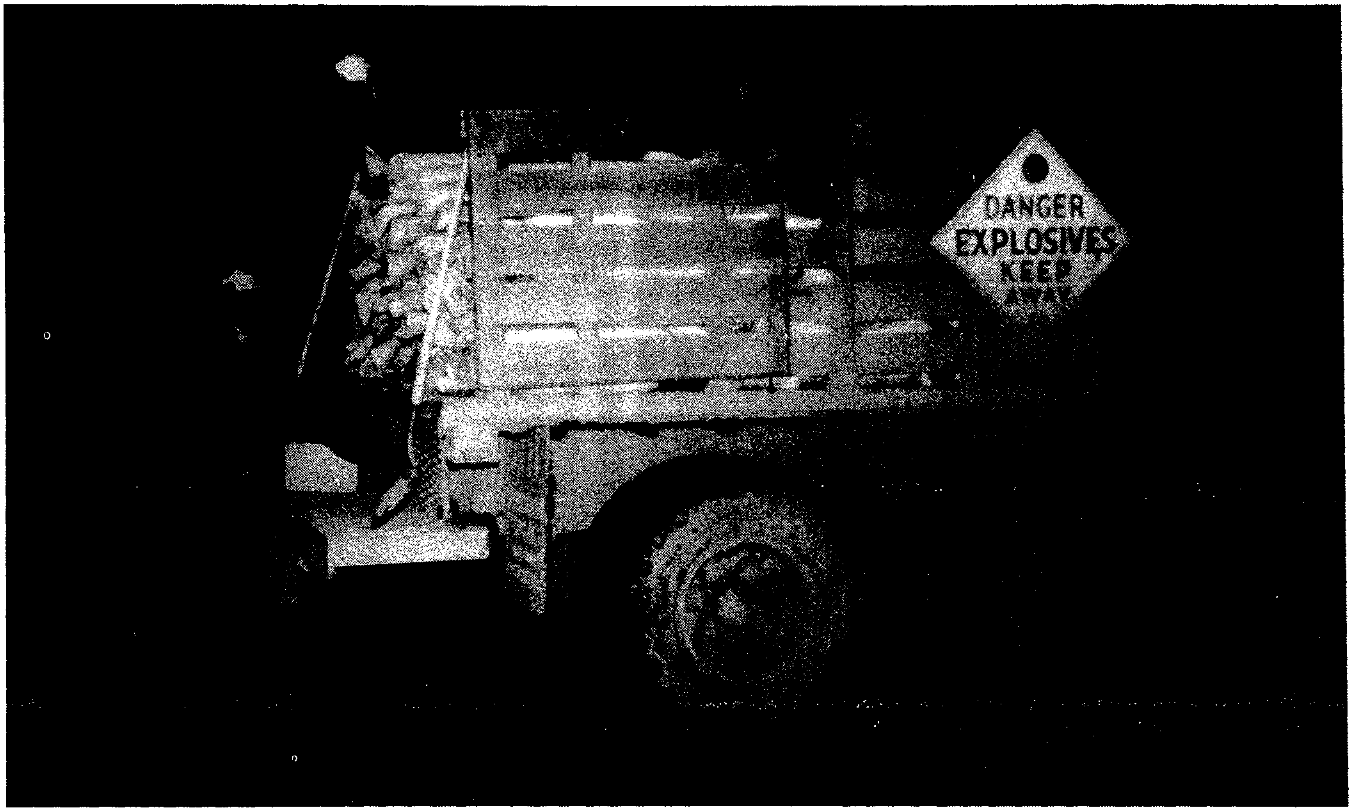

FIGURE 11.—Flatbed truck for transporting packaged explosives.

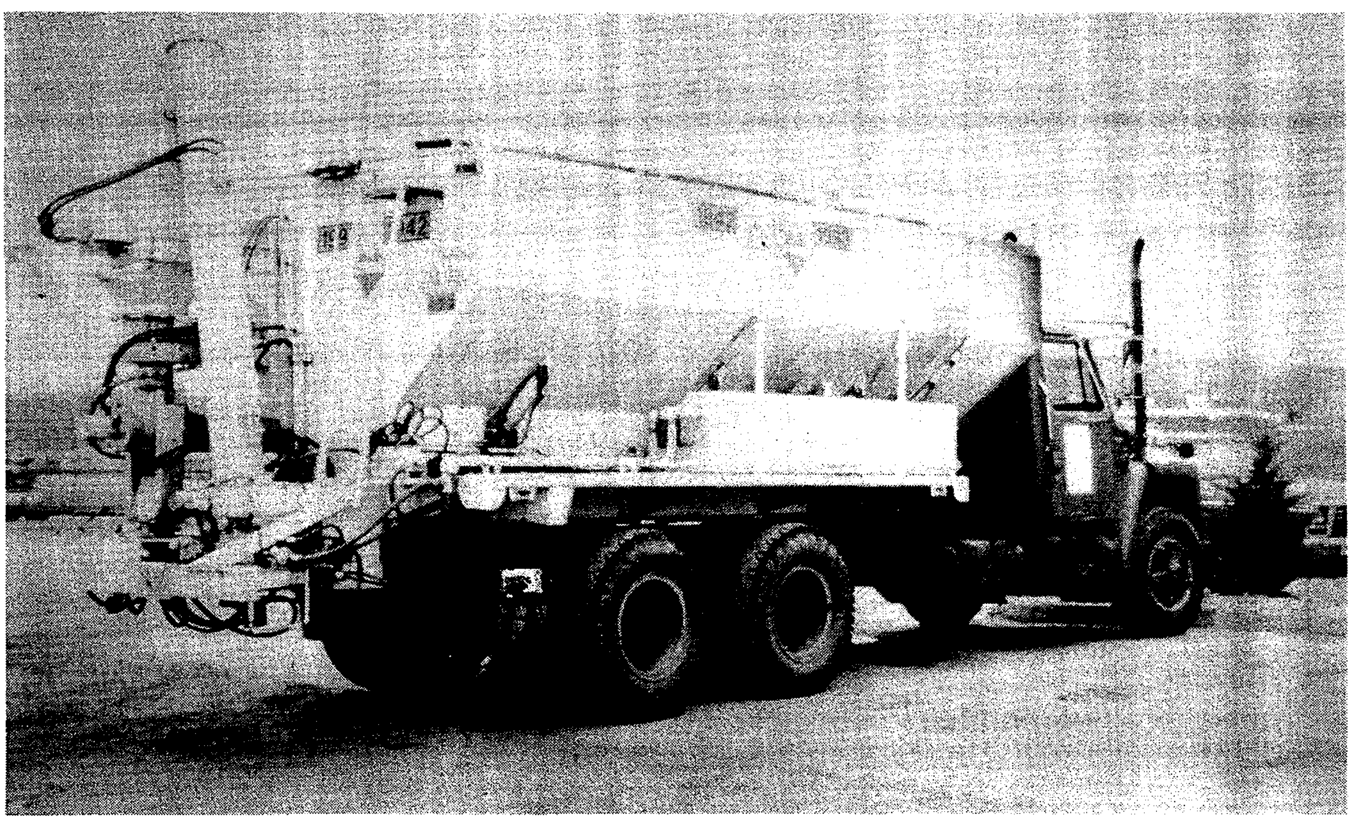

FIGURE 12.—Tank- or drum-type truck for transporting bulk mixture of explosives.

Visibility required by scraper operators includes the ability to see hazards or other moving vehicles while moving from one location to another, the material to be loaded and the general area where loading takes place, the cutting edge of the pan to begin loading, the material level in the pan when filled, and the general area where loaded material is being deposited. Visibility was measured for a number of tasks on two scrapers. Table 7 shows the tasks and task viewing distances with existing and computed illumination levels.

TABLE 6. - Illumination values resulting from task visibility measurements for coal mine explosives trucks

	Existing illuminance, fc	Viewing distance, ft	Computed luminance, fL[1,2]		Reflectance, %	Computed illuminance, fc[1,3]	
			20- to 30-yr-olds	40- to 60-yr-olds		20- to 30-yr-olds	40- to 60-yr-olds
TRUCK 1							
Seen from ground level at rear of truck:							
Edge of bagged explosives.........	1.84	3	1.04	2.53	29.35	3.54	8.64
Detonating cord against primer.....	2.30	1.3	.188	.347	27.83	.68	1.25
Hole slot in primer.	2.28	1.3	.258	.493	32.46	.79	1.52
Black digit on tape measure............	20.70	4.3	.718	1.62	9.90	7.25	16.37
TRUCK 2							
Seen from ground level at rear of truck:							
Edge of blasthole....	[4]150	4.5	0.312	0.612	9.93	3.14	6.16

[1]Calculated for median age in each group.
[2]To convert to candelas per square meter, multiply by 3.426.
[3]To convert to lux, multiply by 10.76.
[4]Supplemental lighting required to make measurements.

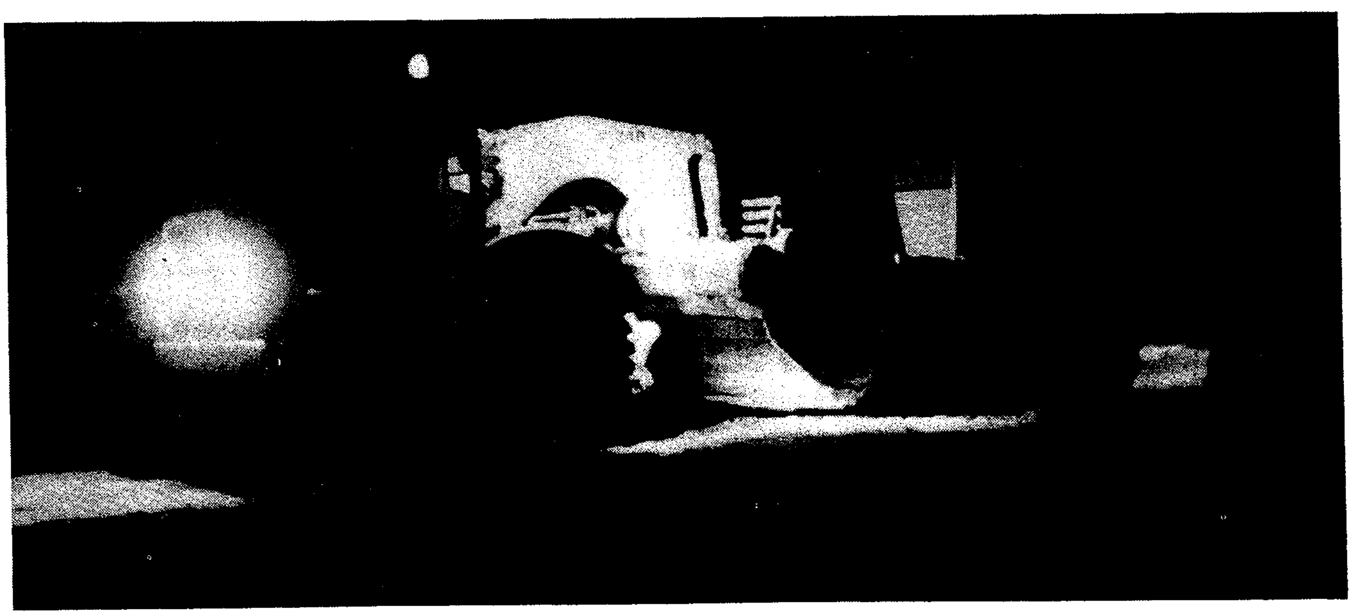

FIGURE 13.—Typical lighting on scraper.

TABLE 7. - Illumination values resulting from task visibility measurements for coal mine scrapers

	Existing illuminance, fc	Viewing distance, ft	Computed luminance, fL[1,2]		Reflectance, %	Computed illuminance, fc[1,3]	
			20- to 30-yr-olds	40- to 60-yr-olds		20- to 30-yr-olds	40- to 60-yr-olds
SCRAPER 1							
Seen from operator's cab:							
Cutting edge of pan.	1.96	16	2.15	6.49	18.88	11.40	34.39
Pothole in road.....	.77	39.6	.635	1.40	20.78	3.06	6.74
Rock on road........	.45	47	1.47	3.97	17.78	8.26	22.32
Top rear edge of loaded pan.........	[4]8.20	14	.204	.378	9.76	2.09	3.87
Seen from ground level at rear push bumper:							
Boarding step.......	[5]12.24	2	.012	.019	2.53	.49	.76
Hand bar for boarding...........	[5]1.79	1.3	.776	1.79	14.52	5.34	12.30
SCRAPER 2							
Seen from operator's cab: Cutting edge of pan..................	54.0	19	0.028	0.046	12.52	0.23	0.36

[1]Calculated for median age in each group.
[2]To convert to candelas per square meter, multiply by 3.426.
[3]To convert to lux, multiply by 10.76.
[4]Extrapolated from other measurements.
[5]Supplemental lighting required to make measurements.

Bulldozers

Track- or wheel-type tractors or simply dozers are indispensable items of equipment for surface mine operators, because of the power they possess to push or pull other machines, objects, etc. Although they can be used in many ways, their main function is to redistribute overburden at dump sites and at dragline and shovel working areas. The illumination system of a typical dozer generally consists of incandescent floodlight luminaires that are mounted in the front and rear, and in some cases, on top of the operator's cab. A track dozer with incandescent lighting is shown in figure 14.

Table 8 shows the results of task visibility and illumination measurements for 11 dozers.

Graders

Motor graders are used to maintain haul roads leading to dump areas and access roads in and around the pit area. Illumination systems are similar to those of loaders and dozers, in that they are mainly incandescent floodlights mounted on the front and rear of the machine and on the top of the operator's cab. An example of a motor grader with an incandescent lighting system is shown in figure 15. General visibility requirements for the grader operator include the ability to see obstacles, hazards, and other vehicles when traveling throughout the mine; the areas adjacent to either end of the blade; the wind row of material being pushed; and the ladder-type steps and hand bars needed for boarding and getting

TABLE 8. - Illumination values resulting from task visibility measurements for coal mine bulldozers

	Existing illuminance, fc	Viewing distance, ft	Computed luminance, fL[1,2]		Reflectance, %	Computed illuminance, fc[1,3]	
			20- to 30-yr-olds	40- to 60-yr-olds		20- to 30-yr-olds	40- to 60-yr-olds
BULLDOZER 1							
Seen from operator's cab:							
Dirt at left blade end................	0.80	23	0.054	0.088	1.25	4.32	7.05
Dirt above blade when pushing load..	135.70	16	.002	.003	.02	10.00	15.00
BULLDOZER 2							
Seen from operator's cab: Dirt at right blade end............	1.56	20	0.063	0.014	1.92	3.26	5.43
Seen from ground level:							
Hand bar above trunnion arm for boarding...........	.41	1.6	2.96	10.27	34.15	8.65	30.09
Edge of trunnion arm step for boarding..	.44	1.6	.021	.033	4.54	.46	.72
BULLDOZER 3							
Seen from operator's cab: Power cable of dragline.............	0.47	42.2	0.492	1.03	21.28	5.25	11.00
BULLDOZER 4							
Seen from ground level:							
Edge of bottom rung of boarding ladder.	0.06	2.1	0.018	0.028	16.67	0.11	0.17
Handhold (rung).....	.03	1.4	.086	.146	100.0	.09	.15
Seen from operator's cab: Top edge of blade against load pushed..............	42.65	14	.421	.864	4.99	8.43	17.30
BULLDOZER 5							
Seen from operator's cab: Left blade end against load pushed..	0.86	15	0.325	0.637	30.23	1.08	2.11
BULLDOZER 6							
Seen from operator's cab: Left blade end against load pushed..	[4]122.40	15.6	0.085	0.145	3.34	2.54	4.34
BULLDOZER 7							
Seen from operator's cab: Left blade end against load pushed..	[4]12.60	15.3	0.188	0.344	23.81	0.79	1.45

See footnotes at end of table.

TABLE 8. - Illumination values resulting from task visibility measurements for coal mine bulldozers--Continued

	Existing illuminance, fc	Viewing distance, ft	Computed luminance, fL[1,2]		Reflectance, %	Computed illuminance, fc[1,3]	
			20- to 30-yr-olds	40- to 60-yr-olds		20- to 30-yr-olds	40- to 60-yr-olds
BULLDOZER 8							
Seen from ground level at rear of machine: Edge of grouzer (step) for boarding..	[4]42.20	2.1	0.001	0.002	0.02	5.00	10.00
BULLDOZER 9							
Seen from operator's cab: Left blade end against muddy load pushed..............	1.51	17.5	0.035	0.056	4.64	0.76	1.20
BULLDOZER 10							
Seen from operator's cab: Top of blade against load pushed..	6.35	13.3	0.132	0.234	8.66	1.52	2.70
Seen from ground level at boarding ladder:							
Bottom rung.........	[4]36.80	2.5	.008	.012	.46	1.78	2.57
Handhold (rung).....	1.32	1.3	.057	.093	61.36	.09	.15
BULLDOZER 11							
Seen from operator's cab:							
Left blade end against ground surface............	1.39	14.8	0.572	1.23	17.27	3.31	7.12
Top right blade end against ground surface............	3.26	14.5	.081	.138	8.28	.98	1.67
Edge of deck outside door of cab........	1.33	3.3	.200	.368	32.33	.62	1.14
Seen from ground level:							
Edge of trunnion arm (step) for boarding	.39	1.7	.010	.015	2.56	.39	.60
Hand bar above trunnion arm for boarding...........	.93	2.8	.005	.007	2.15	.23	.35

[1]Calculated for median age in each group.
[2]To convert to candelas per square meter, multiply by 3.426.
[3]To convert to lux, multiply by 10.76.
[4]Supplemental lighting required to make measurements.

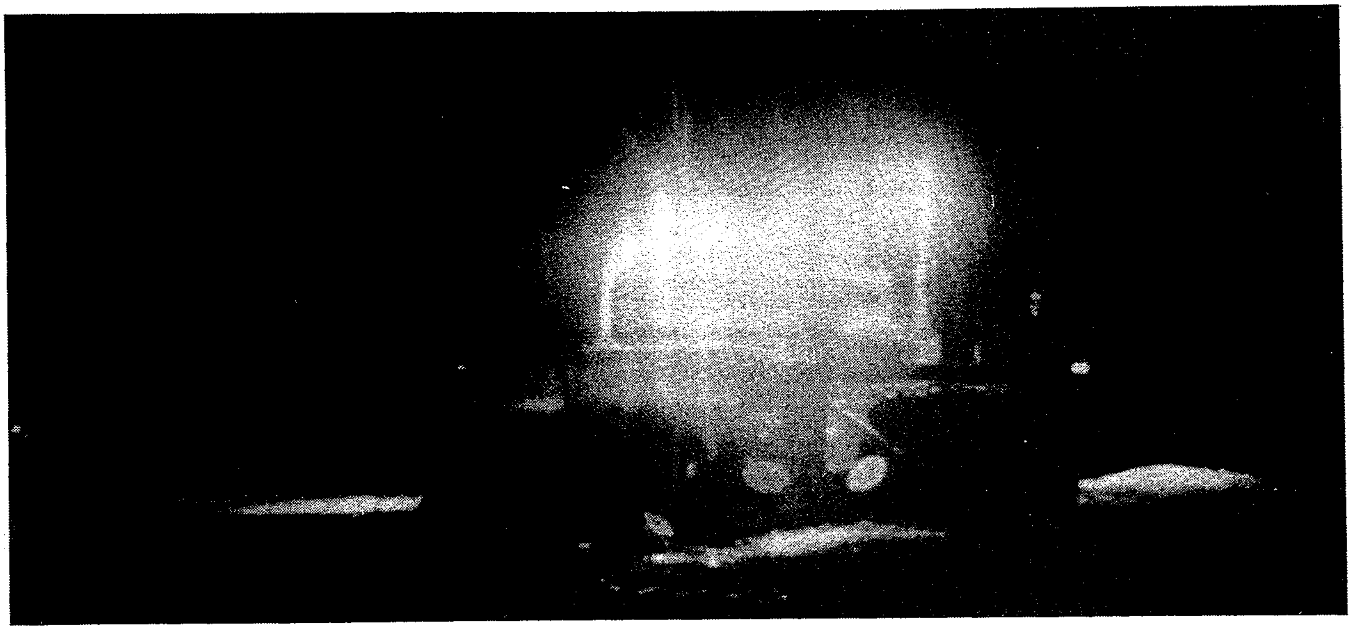

FIGURE 14.—Typical lighting on bulldozer.

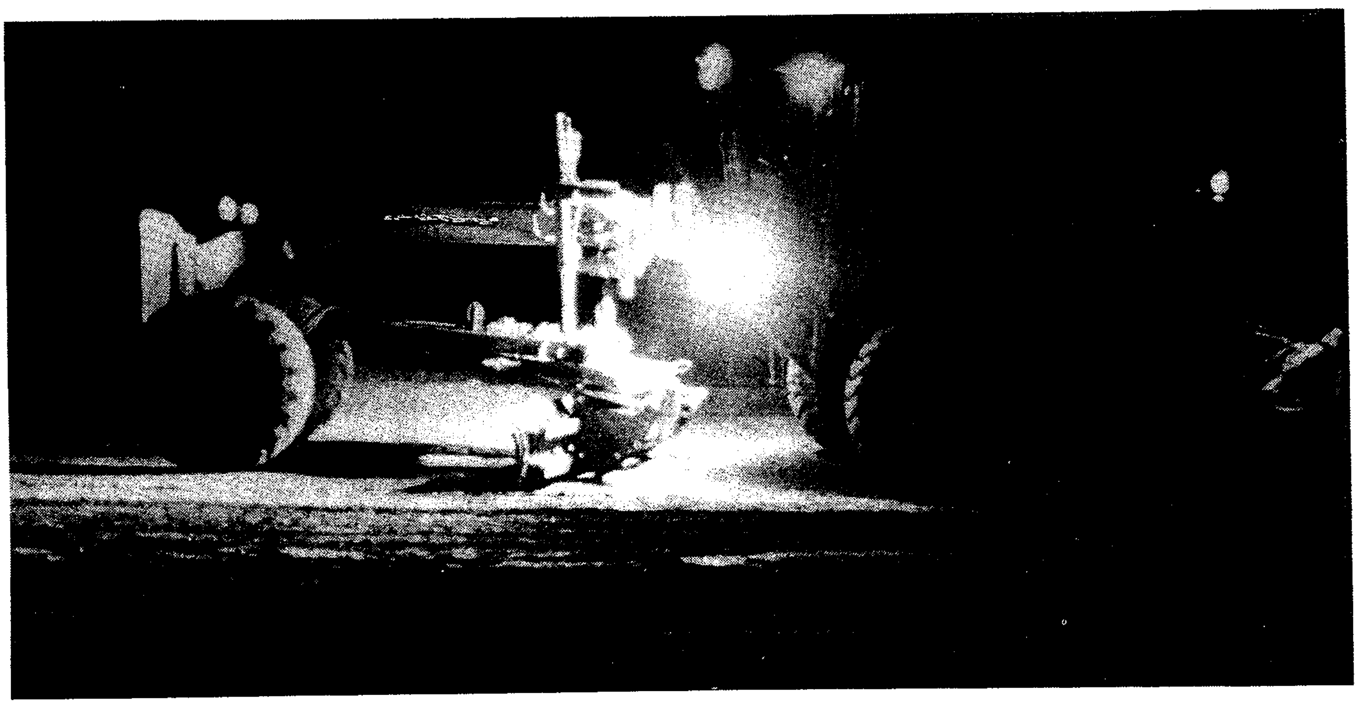

FIGURE 15.—Typical illumination system on motor grader.

off the machine. Table 9 shows the illumination levels with corresponding tasks for four motor graders.

Service Vehicles

Various types of service vehicles are an essential part of coal mining pit operations. Fuel and lubrication trucks (figs. 16-17), which may work in pairs, are used to maintain equipment in the pit area. As their names imply, they are used in replenishing diesel fuel, greasing appropriate parts, and checking and replacing various filters on mobile diesel equipment.

TABLE 9. - Illumination values resulting from task visibility measurements for coal mine motor graders

	Existing illuminance, fc	Viewing distance, ft	Computed luminance, fL[1,2]		Reflectance, %	Computed illuminance, fc[1,3]	
			20- to 30-yr-olds	40- to 60-yr-olds		20- to 30-yr-olds	40- to 60-yr-olds
GRADER 1							
Seen from operator's cab:							
Pothole in road.....	[4]0.31	85	2.57	8.43	29.03	8.84	29.05
Top of wind row at right blade end....	1.04	14.6	.106	.184	4.81	2.20	3.82
Top of left blade end................	6.26	10.7	.014	.021	.96	1.46	2.16
Rock on road........	.44	65	.492	1.03	22.73	2.16	4.53
Clumped dirt at right blade end....	1.35	14.7	5.41	25.76	28.15	19.20	91.51
Seen from ground level at boarding ladder:							
Bottom rung.........	[4].63	1.9	.024	.037	4.76	.50	.78
Hand bar............	[4].11	1.4	.009	.014	9.09	.10	.15
GRADER 2							
Seen from operator's cab:							
Left blade end......	5.63	13.4	0.014	0.021	1.06	1.30	2.02
Right blade end.....	7.23	9.4	.123	.216	14.38	.86	1.50
Seen from ground level at boarding ladder:							
Bottom step..........	2.74	1.9	.320	.625	5.84	5.48	10.70
GRADER 3							
Seen from operator's cab:							
Right blade end.....	2.99	13.3	0.008	0.012	0.67	1.14	1.76
Bottom of left blade end................	1.23	8.7	.007	.010	.81	.87	1.23
Top of left blade end................	1.23	7.8	.027	.043	7.32	.37	.58
Seen from ground level at boarding ladder:							
Bottom step..........	.36	2	.041	.067	22.22	.18	.30
GRADER 4							
Seen from operator's cab:							
Right blade end.....	2.26	9	0.012	0.019	1.33	0.94	1.45
Left blade end......	2.45	13.4	.080	.135	5.31	1.50	2.54
Seen from ground level at boarding ladder:							
Bottom step..........	1.67	1.7	.052	.085	4.19	1.23	2.02

[1]Calculated for median age in each group.
[2]To convert to candelas per square meter, multiply by 3.426.
[3]To convert to lux, multiply by 10.76.
[4]Supplemental lighting required to make measurements.

FIGURE 16.—Truck used for refueling and lubricating equipment.

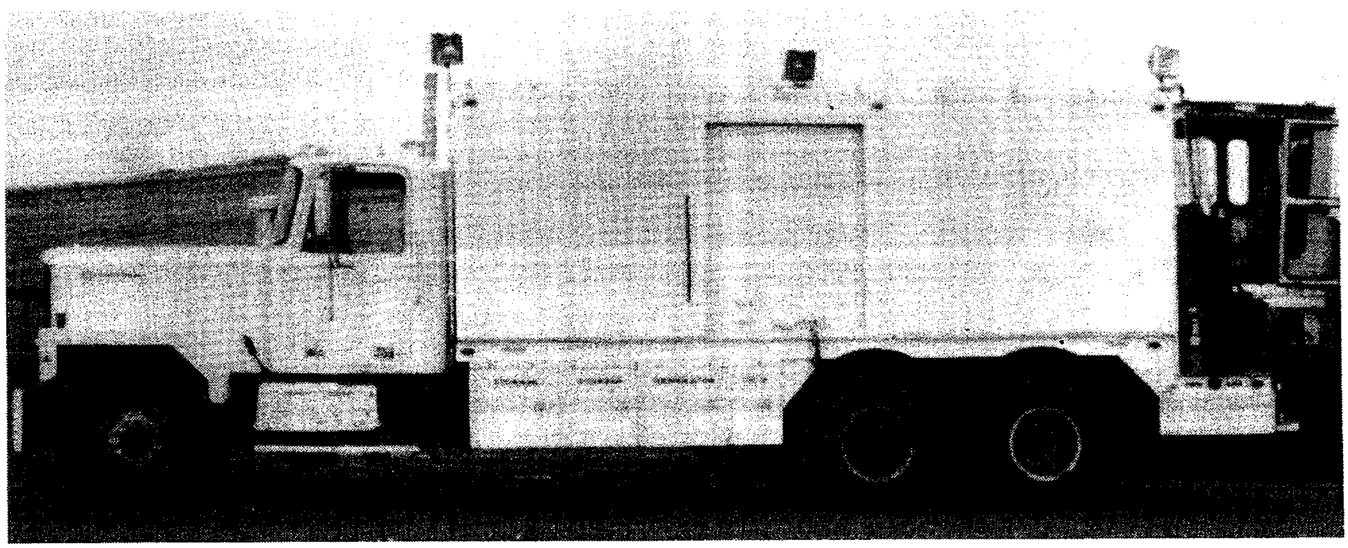

FIGURE 17.—Luminaires mounted on top rear section of lubrication truck.

Illumination for these vehicles is supplied by incandescent luminaires mounted on the truck or handheld lamps or cap lamps. In some cases, quartz halogen luminaires are used. Also, these vehicles rely a great deal on the illumination systems of the equipment which they service for the lighting needed to do their work.

General visibility requirements for operators of these vehicles are basically the same as those for operators of other mobile mining equipment. Tasks involve detecting hazards or other vehicles while driving to and from different working areas within the mine and seeing handholds, handles, and steps when getting in and out of the service vehicles or on and off equipment being serviced. Selected tasks for two fuel trucks and three lubrication trucks are shown in tables 10 and 11 with corresponding illumination levels for each task.

Another type of service vehicle is the water truck, which is used to sprinkle or spray water onto haulage and access roads to allay dust. The primary illumination for watering vehicles, as for some of the vehicles previously mentioned, is the standard high- and low-beam headlights.

TABLE 10. - Illumination values resulting from task visibility measurements for coal mine fuel trucks

	Existing illuminance, fc[4]	Viewing distance, ft	Computed luminance, fL[1,2]		Reflectance, %	Computed illuminance, fc[1,3]	
			20- to 30-yr-olds	40- to 60-yr-olds		20- to 30-yr-olds	40- to 60-yr-olds
TRUCK 1							
Seen from ground level:							
Black digit of fuel meter..............	0.58	2.3	0.109	0.190	8.62	1.27	2.20
Boarding step of cab	.30	2.7	.038	.061	13.33	.29	.46
Hand bar for boarding...........	1.65	1.3	.026	.041	6.67	.39	.62
Seen from corner of walkway behind driver's cab: Edge of walkway along fuel tank.................	.24	4.6	.007	.010	4.17	.17	.25
TRUCK 2							
Seen from ground level:							
Black digit of fuel meter..............	0.70	1.3	0.178	0.325	7.03	2.54	4.63
Nozzle of fuel hose.	1.02	1.5	.167	.304	17.65	.95	1.72
Boarding step of cab	1.03	3	.010	.015	.97	1.03	1.59

[1]Calculated for median age in each group.
[2]To convert to candelas per square meter, multiply by 3.426.
[3]To convert to lux, multiply by 10.76.
[4]Supplemental lighting required to make measurements.

In many cases, water trucks are modified forms of other equipment, such as bottom-dump haul trucks or scrapers. In general, visibility is needed for many of the same types of tasks as required for the above vehicles. Selected tasks for one water truck are shown in table 12 with corresponding existing and computed illumination levels.

SURFACE METAL AND NONMETAL MINES

Surface methods are used to mine a number of M-NM ores besides coal. The types of mines visited during this program included iron ore, phosphate, limestone, and granite quarries. With a few exceptions, most of these mines are operated in much the same way as the surface coal mines with similar equipment and visibility requirements for machinery operators.

The two iron ore mines are large, open pit mines. The ore is mined by the benching method using loading shovels and haul trucks, which transport the ore to a primary crusher. From there it is conveyed by belt to a secondary crusher and then processed into pellets at a plant located adjacent to the mining pit.

The five phosphate mines employ draglines for excavating this very soft nonmetallic ore. The draglines, which are essentially the only type of mobile equipment in operation during nighttime hours, dump the phosphate ore into small pits equipped with high-pressure water guns, which in turn wash the phosphate down into a "well." The slurry formed is

TABLE 11. - Illumination values resulting from task visibility measurements for coal mine lubrication trucks

	Existing illuminance, fc[4]	Viewing distance, ft	Computed luminance, fL[1,2]		Reflectance, %	Computed illuminance, fc[1,3]	
			20- to 30-yr-olds	40- to 60-yr-olds		20- to 30-yr-olds	40- to 60-yr-olds
TRUCK 1							
Seen from ground level at rear of truck:							
Tool in tool box......	1.21	1.3	0.054	0.089	9.09	0.59	0.98
Nozzle of grease hose.	12.80	2	.029	.046	9.22	.32	.50
Chain link of boarding step................	358	3.5	.064	.108	.22	29.32	49.02
TRUCK 2							
Seen from ground level at grease fitting of haul truck wheel: Nozzle of grease hose.....	314	2.1	0.040	0.064	6.30	0.63	1.02
TRUCK 3							
Seen from ground level:							
Nozzle of grease hose.	33.2	1.6	0.068	0.114	3.46	1.96	3.28
Boarding step of cab..	1.19	2	.022	.035	9.24	.24	.38
Hand bar for boarding.	1.63	1.5	.004	.006	3.07	.13	.19

[1]Calculated for median age in each group.
[2]To convert to candelas per square meter, multiply by 3.426.
[3]To convert to lux, multiply by 10.76.
[4]Supplemental lighting required to make measurements.

TABLE 12. - Illumination values resulting from task visibility measurements for coal mine water truck

	Existing illuminance, fc	Viewing distance, ft	Computed luminance, fL[1,2]		Reflectance, %	Computed illuminance, fc[1,3]	
			20- to 30-yr-olds	40- to 60-yr-olds		20- to 30-yr-olds	40- to 60-yr-olds
Seen from operator's cab:							
Vertical stream of water at fillup point..	0.94	117	0.103	0.177	5.32	1.93	3.33
Top of berm at right side of road.........	.69	88	.009	.013	1.45	.61	.92
Water-filled pothole..	1.13	110	.104	.181	5.31	1.97	3.40
Rock on road..........	.64	110	.103	.177	7.81	1.31	2.27
Seen from ground level at boarding ladder:							
Bottom rung...........	[4]2.04	2.5	.016	.025	.98	1.66	2.57
Handhold (rung).......	[4]1.81	1.3	.181	.330	11.05	1.64	2.98

[1]Calculated for median age in each group.
[2]To convert to candelas per square meter, multiply by 3.426.
[3]To convert to lux, multiply by 10.76.
[4]Supplemental lighting required to make measurements.

then pumped through a pipeline to flotation plants where the sand is separated from the phosphate. Investigations at these mines did not include measurements of task visibility.

The six limestone and calcite quarries operate with equipment such as loading shovels, loaders, haul trucks, and unit trains. Task visibility measurements at two of these mines are not included in the report because the VTE was later found to be out of calibration. Circumstances did not permit measuring task visibility at one other of the quarries.

The two granite quarries are rather unique compared with the types and methods of mining previously discussed. The prominent item of equipment is the wire saw, which is used to cut huge slabs of granite from a massive face or wall. The saw consists of helical-shaped steel "wires," roughly 9/32 in. in diameter, which are strung over large sheaves resembling bicycle wheels. The sheaves are mounted on steel tower-like carriages located in channels cut out of either end of the working face. The wire of the saw is one continuous length, up to nearly 1 mile strung around and across the quarry pit, and back and forth across the face to provide for as many as ten 1-1/2-ft cuts. The wires, propelled at speeds up to 45 mph, are used to transport a water slurry consisting of silicon carbide granules fed into the cut from secondary reservoirs on the top of the face. The carbide granules are the "blade" that actually cuts the stone. Once the cut is made to the bottom of the quarry floor, the giant slab of granite (as large as 125 by 1.5 by 100 ft) is broken into smaller size slabs or blocks with drills, jackhammers, regular hammers, shims, and wedges. The slabs are hoisted with cranes and placed on flatbed railroad cars that transport them to a cutting and finishing plant located at or very near the quarry.

The wire saw is the focus of work activity during nighttime hours. Visibility requirements include the inspection of: wires and sheaves at carriages, slurry pumps (at the bottom of each channel) and slurry reservoirs (main and secondary), and the general area on top of the granite face. Data on task visibility were obtained but not included in the report because the VTE was later found to be out of calibration.

Tables 13, 14, and 15 summarize the measurements of task visibility at several of the above M-NM mines. These tables show various visual tasks with existing and computed illumination levels for shovels, blasthole drills, and loaders, respectively.

CONCLUSIONS AND RECOMMENDATIONS

This study shows that the type and extent of illumination varies from mine to mine and seems to be influenced by several factors including mine size, tonnage, and management philosophy. Although operators of surface mines and quarries have generally made positive strides toward providing adequate machine lighting, the results of the study indicate there are some instances where higher levels of illumination are required than are available. The lighting and/or visibility for the visual tasks of machinery operators could be improved in several specific working areas on or about equipment including, among others, draglines, shovels, dozers, loaders, and haul trucks. Some examples and suggested improvements are as follows:

1. The power cable on draglines or shovels must be handled when relocating these machines. Because the cable is frequently dragged along the ground during these procedures, it can become discolored so that it blends with the surface of the ground. In a previous study, Crouch and Vincent[8] reported that by increasing the contrast of the task detail as seen against its background, the visibility of a task can be increased, resulting in lower illumination requirements. The visibility of the power cable in this case could be improved by applying material such as reflective tape, to increase the cable's contrast as seen against its background, the ground surface.

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[8]See footnote 6.

TABLE 13. - Illumination values resulting from task visibility measurements for noncoal mine shovels

	Existing illuminance, fc	Viewing distance, ft	Computed luminance, fL[1,2]		Reflectance, %	Computed illuminance, fc[1,3]	
			20- to 30-yr-olds	40- to 60-yr-olds		20- to 30-yr-olds	40- to 60-yr-olds
SHOVEL 1							
Seen from operator's cab:							
Bottom rear of dipper resting on ground.......	4.43	30	0.050	0.083	10.38	0.49	0.80
Edge of loaded truck bed.	7.22	20	.072	.123	10.39	.70	1.19
SHOVEL 2							
Seen from ground level at boarding ladder:							
Handhold (rung)...........	1.31	1.3	0.004	0.007	6.11	0.07	0.11
SHOVEL 3							
Seen from operator's cab:							
Bottom rear of dipper resting on ground.........	1.28	59.8	0.045	0.073	42.97	0.10	0.17
SHOVEL 4							
Seen from operator's cab:							
Bottom rear of dipper resting on ground.........	3.23	52	0.101	0.173	20.43	0.49	0.84
Seen from landing outside door to house:							
Handrail.................	2.48	1.6	.030	.048	1.61	1.88	2.98
Edge of landing to descend stairs............	1.68	3.7	.034	.054	22.62	.15	.24
Seen from ground level at boarding stairs:							
Bottom step..............	.54	2.6	.080	.135	20.37	.39	.66
Handrail.................	.35	1.3	.075	.125	5.71	1.31	2.19
SHOVEL 5							
Seen from operator's cab:							
Bottom rear of dipper resting on ground.........	8.98	22.8	0.070	0.119	15.37	0.46	0.77
Seen from ground level at boarding ladder:							
Bottom rung..............	4.40	2.4	.045	.073	25.45	.18	.29
Handhold (rung)..........	4.55	1.5	.006	.010	.66	.98	1.50
SHOVEL 6							
Seen from operator's cab:							
Bottom rear of dipper resting on ground.........	4.19	23	0.027	0.043	23.63	0.11	0.18
Seen from ground level at boarding ladder:							
Bottom rung..............	1.12	3.9	.220	.411	26.78	.82	1.54
Handhold (rung)..........	.95	1.8	.202	.373	30.53	.66	1.22

[1]Calculated for median age in each group.
[2]To convert to candelas per square meter, multiply by 3.426.
[3]To convert to lux, multiply by 10.76.

TABLE 14. - Illumination values resulting from task visibility measurements for noncoal mine blasthole drills

	Existing illuminance, fc	Viewing distance, ft	Computed luminance, fL[1,2]		Reflectance, %	Computed illuminance, fc[1,3]	
			20- to 30-yr-olds	40- to 60-yr-olds		20- to 30-yr-olds	40- to 60-yr-olds
DRILL 1							
Seen from ground level:[4]							
Wooden marker to align machine for drilling next hole	0.54	30	0.093	0.160	16.67	0.56	0.96
Power cable	.66	41.3	.425	.871	9.09	4.68	9.58
Straw to mark hole location	10.51	8	.090	.154	9.99	.90	1.54
Remote control	1.42	2.2	.022	.035	9.15	.24	.39
Leveling jack	3.47	32	.150	.270	2.59	5.79	10.43
DRILL 2							
Seen from operator's cab:							
Stem lock against drill pipe	5.28	7	0.093	0.159	41.67	1.40	2.42
Red digit of pressure gauge	6.57	1.3	.486	1.02	66.67	.73	1.53
Cardboard cylinder to maintain opening of blasthole	1.18	10	.050	.081	11.02	.45	.73
Seen from ground level at boarding stairs:							
Bottom step	2.62	3.4	.018	.028	1.53	1.16	1.82
Handrail	2.28	2.2	.105	.183	3.51	2.99	5.20
Seen from landing at head of boarding stairs: Edge of landing to descend stairs	2.24	3.7	.026	.041	1.78	1.47	2.30
DRILL 3							
Seen from operator's cab: Deck bushing (dust-coated) against drill pipe	13.90	7.2	0.029	0.045	10.50	0.27	0.43
Seen from landing outside door to house: Handrail	3.24	1.3	.037	.060	10.80	.34	.56

[1]Calculated for median age in each group.
[2]To convert to candelas per square meter, multiply by 3.426.
[3]To convert to lux, multiply by 10.76.
[4]Operator worked alone and relocated the machine by remote control while standing on ground near operator's cab.

TABLE 15. - Illumination values resulting from task visibility measurements for noncoal mine loaders

	Existing illuminance, fc	Viewing distance, ft	Computed luminance, fL[1,2]		Reflectance, %	Computed illuminance, fc[1,3]	
			20- to 30-yr-olds	40- to 60-yr-olds		20- to 30-yr-olds	40- to 60-yr-olds
LOADER 1							
Seen from operator's cab: Top rear edge of loaded bucket.....	4.47	12	0.080	0.134	25.28	0.32	0.53
LOADER 2							
Seen from operator's cab: Top rear edge of loaded bucket.....	1.35	13	0.053	0.086	25.92	0.20	0.33

[1]Calculated for median age in each group.
[2]To convert to candelas per square meter, multiply by 3.426.
[3]To convert to lux, multiply by 10.76.

2. On dozers and loaders, there is a need to improve visibility and illumination in viewing areas immediately ahead of the machines and adjacent to either end of the blade or bucket, so that the overburden material sliding off to the right or left can be seen. Improvements in these areas can be made by assuring the proper aiming of the light beams of luminaires and/or replacing existing lamps with those of higher intensity.

3. Two other examples involve machinery working near the highwall of the mining pit. A principal danger associated with the highwall is the potential for rocks and other loose material to fall or roll off these nearly vertical walls of overburden onto equipment, such as shovels or loaders, working in the pit below. The danger at waste dumps or stockpiles is the potential for haul trucks to topple over the edge of the highwall and into the pit when dumping waste material. Illumination levels can be increased and the required visibility attained in these cases by using portable light plants (fig. 18), which are available at nearly all mines. The light plants, however, should be placed in locations that would minimize glare for equipment operators working in the areas.

The use and application of the instrumentation, methods, and equations presented in this report will enable a surface mining company to improve its existing levels of luminance and illuminance on or about its mining equipment. Due to the wide variation in lighting at the different mines, the limited time available to take measurements on operating equipment, and the limitations of the instruments used, the data given in the tables are only an indication of the luminances, illuminances, and reflectance factors needed for equipment operators to carry out required tasks safely and efficiently.

The results of this study should provide data useful in efforts to establish illumination standards for surface mines. Additional field work should be done to establish more rigid guidelines.

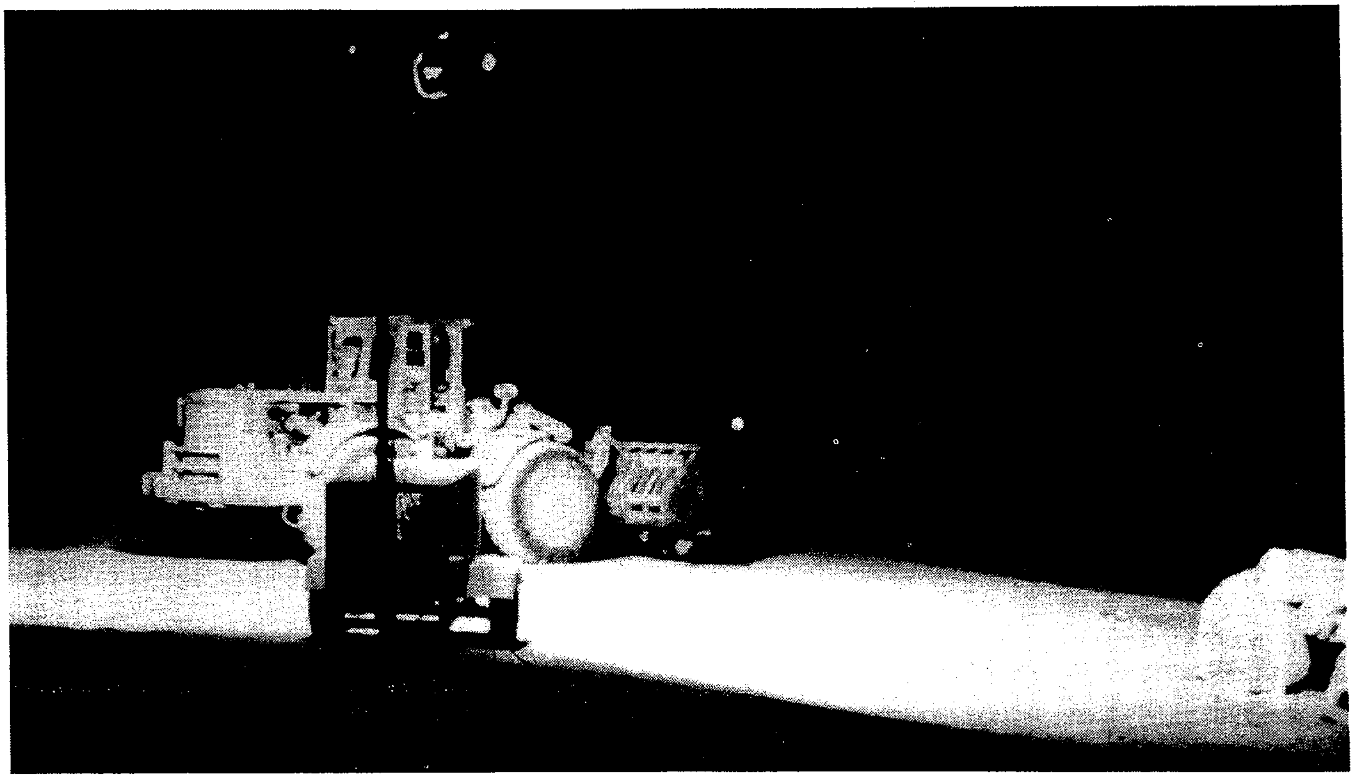

FIGURE 18.—Typical portable lighting unit.

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APPENDIX A.--GLOSSARY OF TERMS, ABBREVIATIONS, AND SYMBOLS[1]

TERMS

Equivalent contrast--a measure of the visibility of a visual task representing the luminance contrast of the reference task with both the visual task and reference task having the same visibility at the background luminance level of the visual task.

Illuminance--density of light flux arriving at a surface.

Illumination--the act of illuminating or state of being illuminated.

Luminance--a measure of the characteristic of being luminous, formerly called brightness.

Luminance contrast--the difference in luminance of a visual task's critical detail and its immediate background, expressed as a proportion of the background luminance.

Reflectance--generally speaking, the ratio of the light flux leaving a surface to the light flux striking a surface.

Threshold contrast--the value of luminance contrast at the visibility threshold.

Transmittance--the ratio of the light passing through a medium to the light striking the medium (illuminance).

Visibility--the quality or state of being perceived by the eye.

[1]References 5 and 7 were primarily used in defining the terms and symbols.

Visibility level--a measure of the extent to which the equivalent contrast of a visual task exceeds the visibility threshold of an observer for the same display at the same level of task background luminance.

Visibility reference function--values of threshold contrast as a function of reference luminance for the visibility reference task, obtained by the reference observer.

Visibility reference task--a 4' luminous disk shown in a pulse train of 0.2-s exposures when used to establish the visibility reference function.

Visibility threshold--the setting on a contrast-reducing visibility meter at which the critical detail of a visual task can barely be seen, such as detection of presence, recognition of spatial detail, recognition of meaning.

Visual performance--generally speaking, the speed and accuracy with which a visual task is performed.

Visual task--the critical detail of objects or surfaces that must be seen to perform a given activity and the immediate background of the objects or surfaces.

Visual task evaluator--an optical instrument that enables an observer to measure visibility by varying the contrast of objects or surfaces seen through the instrument.

ABBREVIATIONS AND SYMBOLS

NOTE.--This list does not include the unit of measure abbreviations listed at the front of this report.

C	Luminance contrast
$\bar{C}$	Threshold contrast
CC	Contrast control
CIE	Commission Internationale De L'Eclairage (International Commission on Illumination)
$\tilde{C}_{ref}$	Reference equivalent contrast
$\bar{C}_{ref}$	Reference threshold contrast
CT	Contrast transmittance
DVM	Digital voltmeter--a numerical value corresponding to the measurement of a level of contrast with the Blackwell model 5 VTE.
E	Illuminance
IES	Illuminating Engineering Society of North America
k_i	Correction constant for VTE model 5
k_o	VTE operator calibration constant
L	Standard population luminance
L_b	Background luminance
L_{ref}	Reference luminance
L_t	Target (critical detail) luminance
m_1	Visibility threshold multiplier for age
M-NM	Metal and nonmetal
R	Reflectance
RCS_{ref}	Relative contrast sensitivity
VL	Visibility level
VL_A	Adjusted visibility level
VL_R	Raw visibility level
VTE	Visual task evaluator

APPENDIX B.--CALIBRATION AND ANALYSIS PROCEDURES

CALIBRATION FOR THE VTE USER

The following discussion is excerpted in part from Blackwell (8).[1] In order to adjust visibility data for differences in the sensitivity between a VTE user and the average 20- to 30-yr-old of the normal population, a calibration constant, k_o, was determined for the Bureau VTE user. In the Bureau's illumination laboratory, a series of 10 tests was conducted using a black, matte, circular target on a white, matte-paper background. The size of the target was adjusted to the size of a 4' disk by increasing the distance of the user from the target. The adjustment was made by the formula

$$4' \text{ target} = \frac{x}{d}(3{,}436), \quad \text{(B-1)}$$

where x = diameter of target, in;

and d = user distance, in.

Once the test target was set up, a total of 10 VTE readings were taken (that is, the contrast control dial was set to visibility threshold 10 times). Values in degrees were read from the contrast control of the VTE and were converted to digital voltmeter units (DVM) by the equation

$$CC = 350 - 40\ DVM, \quad \text{(B-2)}$$

where CC = contrast control reading, deg;

and DVM = unit of measure of threshold contrast.

The DVM values were summed, averaged, and then used in conjunction with the graph in figure B-1 to obtain a value of CT. The luminance contrast C was determined for each test by the equation

$$C = \left| \frac{L_b - L_t}{L_b} \right|, \quad \text{(B-3)}$$

where L_b = luminance of the background;

and L_t = luminance of the target.

Then, the VTE user's threshold contrast for a 4' disk target under VTE model 5 conditions is

$$\bar{C}_o = (C)(CT). \quad \text{(B-4)}$$

Using the external luminance (L_b from above) and the graph in figure B-2, the threshold contrast $\bar{C}_{np}$ can be obtained for the average normal user in the 20- to 30-yr-old age group. Note that the graph takes into account the overall transmittance (0.08) of VTE model 5. The user's calibration constant is given then by

$$k_o = \bar{C}_{np}/\bar{C}_o. \quad \text{(B-5)}$$

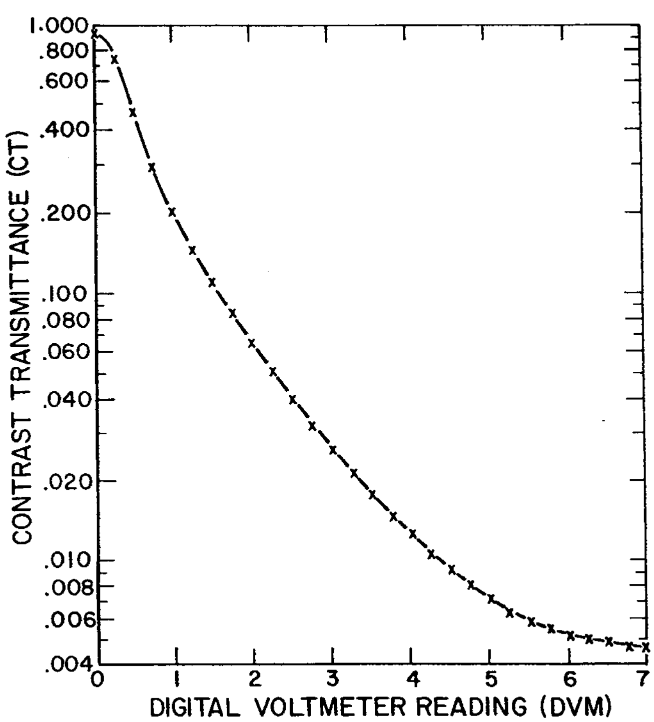

FIGURE B-1.—Contrast control calibration for VTE model 5. (Courtesy H. R. Blackwell, Visioneering Laboratories)

[1] Underlined numbers in parentheses refer to items in the list of references preceding appendix A.

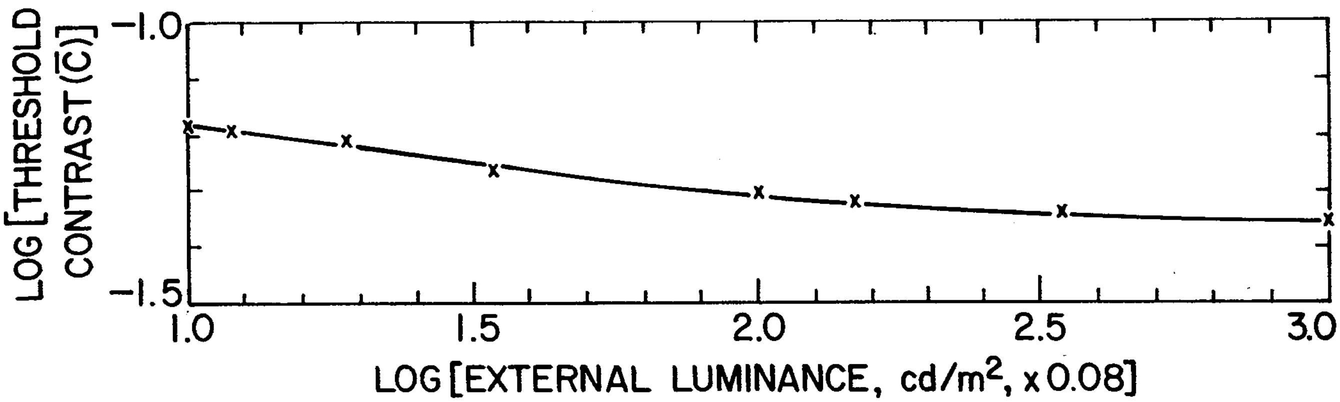

FIGURE B-2.—Normal population data to determine calibration constant for users of VTE model 5. (Courtesy H. R. Blackwell, Visioneering Laboratories)

A sample of calculations to determine k_o for 1 of the 10 laboratory tests follows:

L_t and L_b were measured with a Pritchard photometer and found to be 2.11 fL and 40.6 fL, respectively. The task contrast is calculated as

$$C = \left| \frac{40.6 - 2.11}{40.6} \right|$$

$$= 0.948.$$

The VTE's contrast control dial was set to visibility threshold 10 times, to give an average value of 1.88. From figure B-1, at DVM = 1.88, CT = 0.073. The VTE user's threshold contrast is then

$$\bar{C}_o = (0.948)(0.073)$$

$$= 0.0692.$$

Next, the external luminance (L_b) is changed to SI units:

$$(40.6 \text{ fL}) \left(3.426 \frac{\text{cd/m}^2}{\text{fL}}\right) = 139.1 \text{ cd/m}^2.$$

Taking into account the 8% transmission of the VTE and taking the logarithm gives

$$(139.1)(0.08) = 11.13;$$

$$\log 11.13 = 1.05$$

From figure B-2 the log of the external luminance equal to 1.05 corresponds to log -1.19 for $\bar{C}_{np}$.

The antilog of this value is 0.0646. Then $k_o = \frac{0.0646}{0.0692}$,

$$= 0.9335.$$

Thus, this value and those calculated for nine other lab tests gave an average value of 0.97 for k_o.

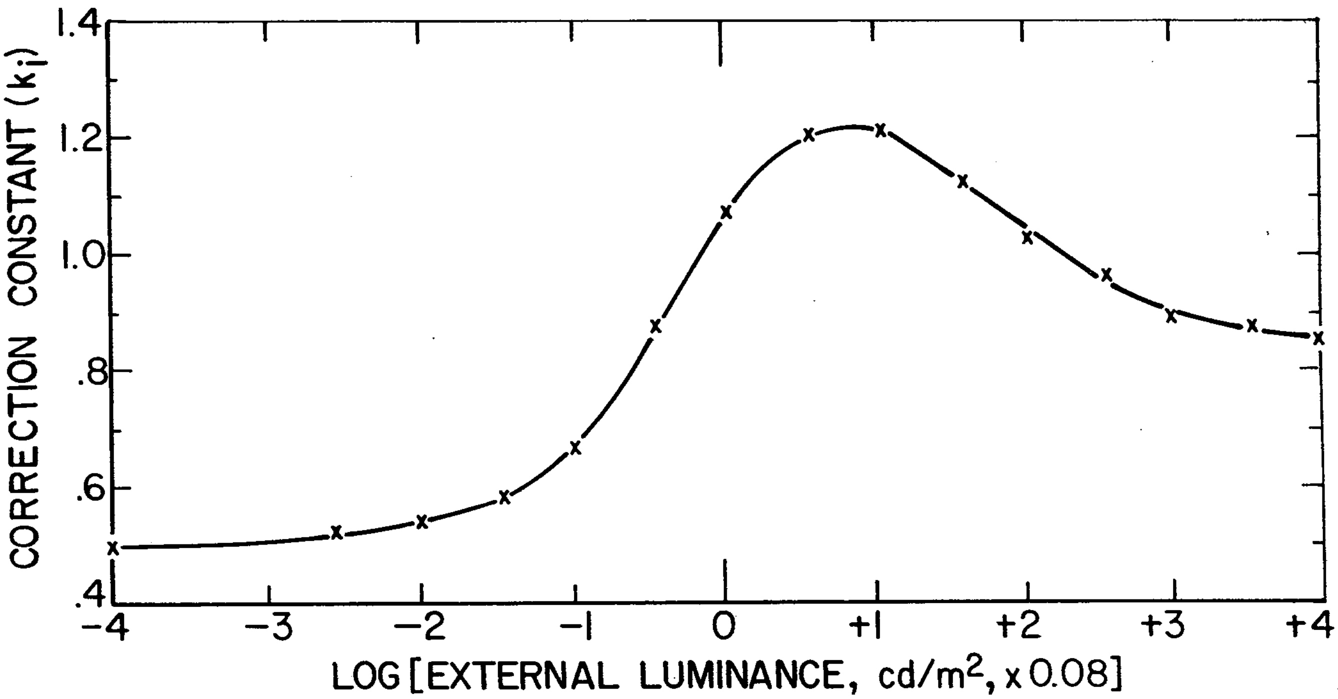

FIGURE B-3.—Correction constant for VTE model 5. (Courtesy H. R. Blackwell, Visioneering Laboratories)

ANALYSIS OF FIELD DATA

The field data, which included raw visibility level (VL_R) values for the different mining tasks, were adjusted further to take into account the difference between the visual conditions of the model 5 VTE and the single-glimpse conditions used in CIE Report 19/2. The differences are the reduction in luminance imposed by the VTE and the use of long exposures rather than 0.2-s pulses. Using the graph in figure B-3 with the logarithm of the external luminance measured for each task in the field, a correction constant for the VTE model 5, k_l, was determined. Then the adjusted visibility level values (VL_A) were calculated by

$$VL_A = VL_R \left(\frac{k_l}{k_o} \right). \qquad \text{(B-6)}$$

The visibility data collected during mine visits were analyzed according to the *indirect method* of CIE Report 19/2. The illumination levels for each mining task were computed by the equations that follow. Their use is shown in a set of sample calculations. A full explanation of the method can be found in CIE Report 19/2.

$$\bar{C}_{ref} = 0.05936 \left[\left(\frac{1.639}{L_{ref}} \right)^{0.4} + 1 \right]^{2.5}. \qquad \text{(B-7)}$$

$$VL = \tilde{C}_{ref}/C_{ref}. \qquad \text{(B-8)}$$

$$VL = \tilde{C}_{ref} \left(\frac{RCS_{ref}}{0.0923\ m_l} \right). \qquad \text{(B-9)}$$

$$\text{Age:}\quad 20\text{–}42\ \text{yr},\ m_1 = 1.000 + 0.00795\ (A-20),$$

$$42\text{–}64\ \text{yr},\ m_1 = 1.175 + 0.0289\ (A-42), \qquad \text{(B-10)}$$

where m_1 = the visibility threshold multiplier,

and A = age, yr.

$$RCS_{ref} = 1.555\left[\left(\frac{1.639}{L}\right)^{0.4} + 1\right]^{-2.5}. \qquad \text{(B-11)}$$

Using the equations above, the illumination levels for each mining task were calculated, as illustrated in the following sample calculations. The L_b measured for each mining task is first converted to candelas per square meter and then can be used in equation B-7 for L_{ref} to obtain a value of C_{ref}. In this case, L_b was equal to 0.03426, so:

$$\bar{C}_{ref} = 0.5936\left[\left(\frac{1.639}{0.03426}\right)^{0.4} + 1\right]^{2.5}$$

$$= 4.6.$$

Using equation B-8 with this value of $\dot{C}_{ref}$ and a value of 2.2 for VL (equivalent to VL_A), $\tilde{C}_{ref}$ can be found.

$$\tilde{C}_{ref} = (2.2)(4.6) = 10.1.$$

This value of $\tilde{C}_{ref}$ is subsequently inserted into equation B-9 with VL = 8.0 and m_1 = 1.040 (from equation B-10, where A = 25) to determine the appropriate value of RCS_{ref}.[2]

$$RCS_{ref} = \frac{(0.0923)(8.0)(1.040)}{(10.1)}$$

$$= 0.076.$$

The luminance of the task is then calculated by substituting the resulting value of RCS_{ref} into equation B-11, which is rearranged to solve for L.

$$L = 1.639\left[\left(\frac{1.555}{0.076}\right)^{0.4} - 1\right]^{-2.5}$$

$$= 0.195\ \text{cd/m}^2,$$

or $(0.195\ \text{cd/m}^2)(0.292) = 0.057$ fL.

This is the luminance level of the task for the average 25-yr-old user of the normal population.

---

[2]A VL of 8 is the visual performance criterion used in the IES method for prescribing illumination (9).

The illuminance or the amount of illumination on the task is computed by using the luminance or reflectance factor (R) of the task background under actual lighting conditions (also reference conditions). In this instance, R is 1.25%. Since the surfaces are largely diffusing, the equation describing a basic law of lighting can be used:

$$R = \frac{L}{E}, \tag{B-12}$$

where L = luminance;

and E = illuminance.

Inserting the values produces

$$E = \frac{0.057\ \text{fL}}{0.0125}$$

$$= 4.56\ \text{fc},$$

or

$$(4.56\ \text{fc})(10.76) = 49.1\ \text{lx}.$$

The level of illumination was also calculated for the most commonly found older worker. A random sample of 81 equipment operators was collected from 7 surface coal mines during the study. Of this total, 38% were found to be in the 40- to 60-yr age group.

Using equation B-10, and 50 yr as the average age of this group, the factor m_1 is determined as follows:

$$m_1 = 1.175 + 0.0289\ (50 - 42),$$

$$= 1.406.$$

A new value of RCS_{ref} is then calculated with this value of m_1 and the previously determined $\bar{C}_{ref}$.

$$RCS_{ref} = \frac{(0.0923)(8.0)(1.406)}{(10.1)},$$

$$= 0.103.$$

As shown in the previous calculations for the 20- to 30-yr age group, this value of RCS_{ref} is entered in equation B-11 to obtain the task luminance, which in this case was 0.304 cd/m^2 or 0.089 fL. Then, once again with 1.25% as the reflectance, 7.12 fc or 76.6 lx was calculated as the illumination on the task.

Note that the preceding calculations for illumination did not account for other factors (discussed in CIE Report 19/2) that affect task visibility and, consequently, illumination, such as contrast rendition, disability glare, and transient adaptation effects. Inclusion of these additional factors in calculating illumination required additional measurements that were beyond the scope of this study.

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