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APPROVED ELECTRIC LAMPS
FOR MINERS

BY

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AND

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APPROVED ELECTRIC LAMPS FOR MINERS.

By H. H. CLARK and L. C. ILSLEY.

INTRODUCTION.

In various publications relating to safety in mining the Bureau of Mines has called attention to the hazards attending the use of open-flame lamps. An open-flame lamp is a potential source of danger in any coal mine. It may start a fire in a dry mine or an explosion in a gaseous mine.

The type of open-flame oil lamp now used in mines is the product of long evolution; its principal merit is simplicity. That such a light is unsafe in an atmosphere containing gas (methane) is evident, and Sir Humphrey Davy immeasurably increased safety in coal mines when he found means of protecting a lamp flame so that it would not readily ignite gas. The safety lamp, however, gives less light than the open-flame lamp, is not as simple in construction, is more cumbersome, and must be carried in the hand. Consequently, some miners are reluctant to abandon the open-flame lamp for the safety lamp, and risk their own lives and the lives of their fellow workers with the one rather than to be hampered by the other.

When small electric bulbs, with their clear, white light, and small electric storage batteries became available, the advantage of combining these elements for a miner's lamp seemed manifest. The combination looked simple and safe, but was soon found to have elements of danger and weakness peculiar to itself.

The Bureau of Mines showed, in 1911, that the breaking of a miniature electric bulb in an inflammable mixture of gas and air might ignite the mixture, so that only the fragile glass of the lamp bulb might stand between the miner and injury or death. There was also a possibility that sparks from the small battery would ignite gas, and the accidental spilling of the contents of a battery on the miner's clothing or skin was a possible source of injury.

The first portable electric miner's lamps that were carried in the hand, or with the battery strapped to the back and the light carried on the head, were exceedingly crude and were designed without appreciation of the sources of danger. The possibility, however, of

producing a safe and practical miner's lamp by the proper combination and design of the elements available promised to increase safety so greatly that the Bureau of Mines attempted to stimulate better design and construction by careful investigations and the establishment of an approval system that would be an assurance to the miner and an advantage to the maker of the lamp. As a result various manufacturers submitted types of lamps, cords, and bulbs for test and cooperated with the bureau in efforts to so improve the safety features of these devices that the lamps would pass specific tests for approval.

SCOPE OF REPORT.

This bulletin describes the development of a number of types of lamps that meet the requirements, and discusses in detail the features and qualities of these lamps, which in November, 1916, were being put into use by mine operators in this country at the rate of about 2,000 a week.

Those lamps that meet a certain minimum specification are approved by the Bureau of Mines. No manufacturer is required to obtain this approval, but the manufacturers have voluntarily submitted their lamps for investigation and criticism. None of the lamps submitted to the bureau was found acceptable in its original form, and the cooperation with the Bureau of Mines of the makers of lamps, bulbs, and cords has extended over the past three years, and the art of making safe miner's electric lamps has thereby been developed much more rapidly than would have been the case had the development been solely the result of commercial exploitation. Also, it is believed that by this method the mining public has been saved expensive and dangerous experiments, which might have cost many lives and for a time condemned the electric lamp as an impracticable device.

The first specification of the Bureau of Mines as to conditions and requirements for testing electric mine lamps was set forth in Schedule 5,^a issued in April, 1913, and the requirements were limited to the prevention of gas ignition. Three lamps were tested and approved under this schedule. Accumulated experience by the bureau indicated the desirability of a broader basis of approval, and another schedule, Schedule 6,^b was issued in February, 1914, which was revised to the present form (Schedule 6A) in February, 1915. Schedule 6A, which is given in full on pages 45 to 53, includes requirements for both the safety and the practicability of the lamp. The

^a Fees for testing permissible portable electric lamps, character of tests, and conditions under which lamps will be tested; Bureau of Mines, 1913, 8 pp.

^b Procedure for establishing a list of permissible portable electric mine lamps, Bureau of Mines, 1914, 12 pp.

original approvals under Schedule 5 were withdrawn and the lamps were retested in accordance with Schedule 6A, and a broader and more comprehensive approval issued to those lamps that passed the later tests.

The bureau grants its approval as an indication of its confidence in the excellence of the lamp as a safe and practical device for lighting mines, especially those mines in which there may be inflammable or explosive mixtures of gas and air. The approval is conferred only after thorough examination and tests have shown that the lamp reaches the standard established by the bureau.

Seven portable electric mine lamps had been approved prior to August, 1916, as follows: Edison lamp, approval No. 10, approved February 24, 1915; Manlite lamp, approval No. 11,^a approved July 16, 1915; Concordia hand lamp, approval No. 12, approved July 26, 1915; Wico lamp, approval No. 14, approved June 10, 1916; Concordia cap lamp, approval No. 15, approved June 17, 1916; General Electric lamp, approvals No. 13 and No. 13A, approved July 11, 1916; Pioneer lamp, approval No. 16, approved July 21, 1916.

Each of these lamps is identified by a plate that bears the seal of the Bureau of Mines, the approval statement, and the number of the approval. No lamp is considered as approved unless it bears this plate.

ACKNOWLEDGMENTS.

Acknowledgment is made of the helpful cooperation that has been given by the manufacturers of the various lamps investigated and approved, and by the manufacturers of electric conductors who made and submitted for test special types of lamp cords. Special acknowledgment is due to Messrs. R. P. Burrows and P. F. Bauder, of the National Lamp Works of the General Electric Co., and Mr. C. M. Bunnell, of the Edison Lamp Works of the General Electric Co., for their successful efforts in developing satisfactory bulbs for mine lamps.

The authors are also indebted to Mr. J. T. Jennings, electrical engineer of the Philadelphia & Reading Coal & Iron Co., for information based on his broad experience with portable electric mine lamps in actual service.

HISTORY OF THE INVESTIGATION.

At the outset of the bureau's work on electric mine lamps little reliable information on such lamps seemed to be available, for the lamps had not been used extensively then, although some pioneer work had been done by several manufacturers. The development of

^a Approval rescinded for cause April 23, 1917.

those lamps that have since received the bureau's approval was either in a very early stage or had not started.

IMPORTANCE OF DEVELOPING AN ELECTRIC LAMP FOR MINERS.

The bureau's attention was given to portable electric lamps for miners because the use of such lamps would manifestly decrease the hazards of mining operations by the elimination of flames (either open or inclosed) and by providing more light in a more convenient form than the safety lamp. Although the investigation of portable electric lamps was undertaken wholly in the interest of safety, the bureau was not concerned exclusively with the safety of the lamp. An electric lamp was not a relatively dangerous piece of equipment that was indispensable to the operation of mines, for other lamps were available, but on the contrary was a relatively safe piece of equipment, not useful unless practicable, and, if practicable, very desirable.

It was the bureau's hope that the electric lamp could be made so practicable that the miner would avail himself of the advantages of its safety features, as it was manifestly futile for the bureau to urge the adoption of an impracticable device, no matter how safe it might be. Therefore the bureau undertook to conduct examinations and tests and to approve those lamps that were found to be safe and practicable for general service in mines, in order to advance as rapidly as possible the manufacture of portable electric mine lamps and to avert the possibility of having a desirable safety device condemned on account of repeated failure in service of impractical forms.

ESSENTIAL QUALIFICATIONS OF ELECTRIC MINE LAMPS.

Safety is a prime requisite for any mine lamp and was the first consideration of the bureau's engineers, who investigated three possible dangers: The liability of the lamps to cause ignitions of gas, their tendency to go out unexpectedly, and the liability of the electrolyte being spilled.

A lamp must be practicable or it is useless as a safety device. The practicability of a portable electric mine lamp is measured by ability to satisfy completely the requirements of the user, which are as follows:

1. The lamp shall produce for the necessary period a suitable amount of properly distributed light.
2. The lamp shall repeat this production whenever required with a minimum number of interruptions and at a cost commensurate with the benefits received.
3. The lamp shall not spill or leak electrolyte.

4. The lamp shall not be heavy enough to be a burden to the user.

After all of the lamps available at the outset of the investigation were examined and numerous preliminary tests had been made, it was decided that the determination of the safety and practicability of a portable electric mine lamp as set forth above required the investigation of the qualities enumerated below:

Liability to ignite gas.

Tendency to unexpected extinction.

Liability to spill electrolyte.

Light-producing capacity—

(1) Amount—

(a) Candlepower.

(b) Flux.

(2) Distribution—

(a) Angle of light stream.

(b) Smoothness.

(3) Time of burning.

Bulb characteristics.

Life of batteries.

Life of cords.

Mechanical and electrical characteristics—

(1) Durability.

(2) Reliability.

(3) Ease of repair.

Schedule 6A, based on the above analysis, sets forth the requirements that the bureau considers indispensable to the approval of portable electric mine lamps and states the test procedure that is followed in making the investigation. The tests reported in this bulletin are based upon the requirements of that schedule.

QUALITIES INVESTIGATED AND TEST PROCEDURE.

LIABILITY TO IGNITE GAS.

Previous experiments of the bureau, reported in Technical Paper 47,^a had demonstrated that bulbs such as are used in miners' electric lamps can ignite explosive mixtures of mine gas and air if the bulbs are broken while the filaments are glowing at their normal operating temperature. The bureau had, therefore, prescribed in its testing requirements that mine lamp outfits must be provided with a device that would extinguish the filaments if the bulbs were broken. The standard tests to determine the effectiveness of such devices were conducted, in general, as follows:

The headpiece of the lamp was placed in a box that was filled with the most explosive mixture of natural gas—natural gas supplied to

^a Clark, H. H., Portable electric mine lamps; Tech. Paper 47, Bureau of Mines, 1913, 8 pp.

the city of Pittsburgh—and air, and the bulbs were then broken while glowing with normal brilliancy. The breaking was accomplished by means of a tool mounted on the end of a sliding rod and shaped like a miner's pick (Pl. I) that was directed successively at different points in the headpiece, against which it was driven with considerable force by means of a wooden mallet. If, as a result of these tests, a bulb was broken without becoming extinguished, the safety device was considered to have failed, even though the gaseous mixture was not ignited.

Tests were also made without the use of gas by striking the headpiece a violent blow with a hammer, a mallet, or a short-handled pick (see Pl. II), or by swinging the headpiece on its cord against stone, iron, or wood. If by this treatment a bulb was broken but not extinguished by the safety devices these were considered to have failed. A single failure of the safety devices made it necessary to redesign them.

Tests reported in Technical Paper 47^a showed that gas ignition as the result of noninductive sparks produced by the batteries of portable electric mine lamps was a remote contingency, but might occur if the current broken was sufficiently large. A safe maximum value of current for a single cell of lead-acid storage battery was found by test to be 125 amperes, and for two cells of alkaline storage battery (the usual grouping in mine lamps) to be 85 amperes. Tests were therefore made to determine whether or not these currents could be exceeded under any conditions of service, normal or accidental; if excessive currents could be obtained changes in construction were required.

The "standard" short-circuit test was made by connecting the battery to be tested directly across an ammeter in series with a resistance equal to the resistance that the lamp circuit would have if a complete short circuit existed just outside the battery casing.

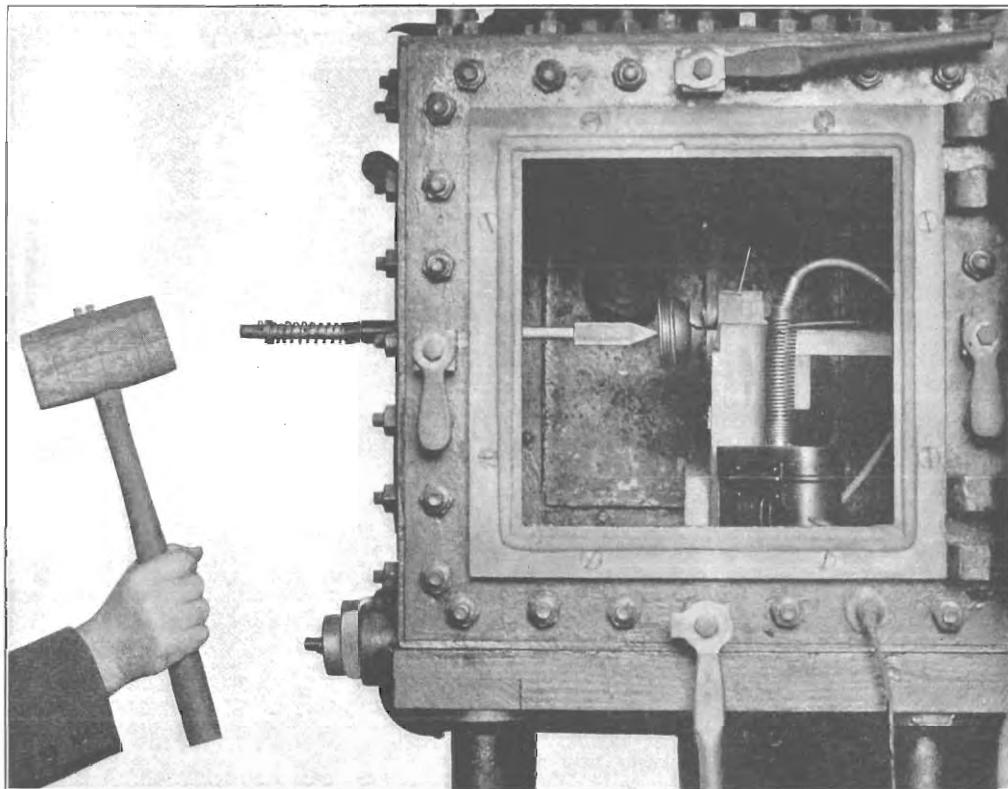
TENDENCY TO UNEXPECTED EXTINCTION.

This quality bears on safety and is likely to exist in lamps of inferior design and construction on account of loose contacts, low capacity, or poorly designed safety devices.

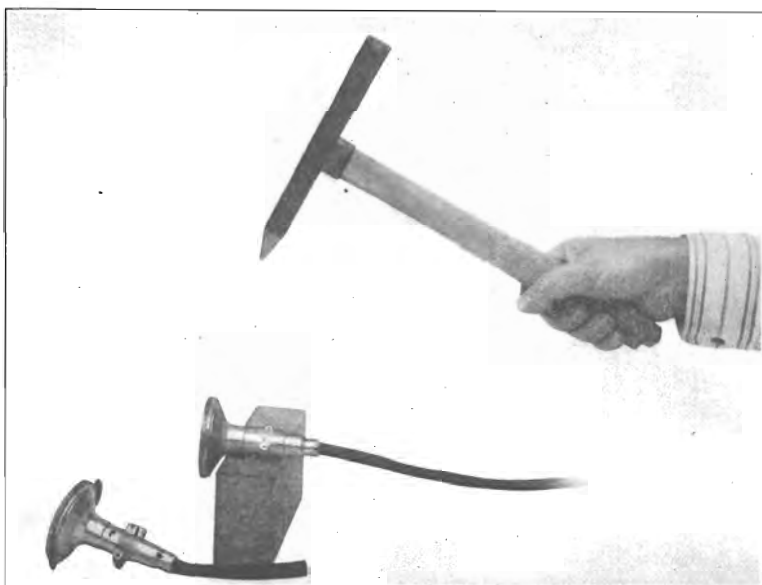
The standard method of investigating the tendency to unexpected extinction as the result of jars or shocks consisted in dropping the headpiece of cap-lamp equipments, and the hand lamp complete, on a concrete floor from a height of 6 feet.

The likelihood of extinction caused by inferior construction giving rise to uncertain contacts was determined by inspection and confirmed by actual experience in operating the lamps in connection with the bulb-life tests made in the laboratory.

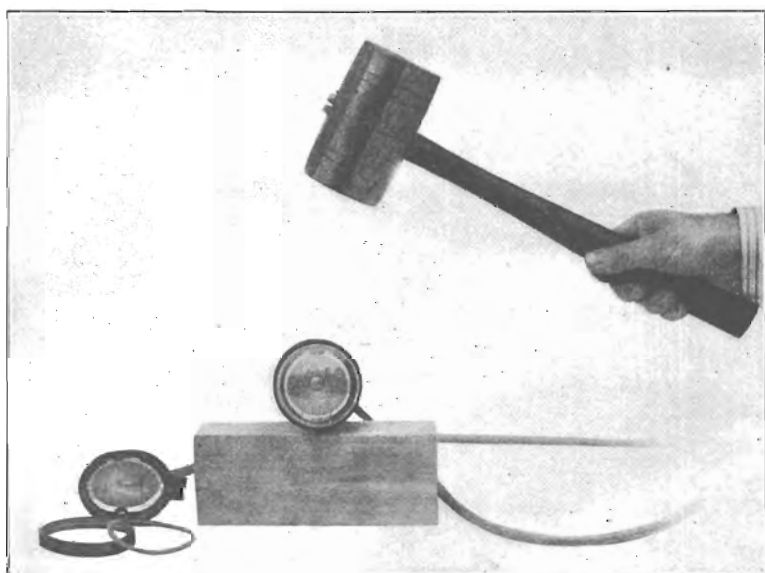
^a Clark, H. H., Portable electric mine lamps; Tech. Paper 47, 1913, pp. 7-10.



EQUIPMENT FOR TESTING SAFETY DEVICES OF ELECTRIC MINER'S LAMP IN EXPLOSIVE MIXTURE OF GAS AND AIR.



A. TESTING SAFETY DEVICES OF AN ELECTRIC MINER'S LAMP BY STRIKING IT WITH A PICK.



B. TESTING SAFETY DEVICES OF AN ELECTRIC MINER'S LAMP BY STRIKING IT WITH A MALLET.

LIABILITY TO SPILL ELECTROLYTE.

The liability of the electrolyte being spilled bears on safety, and the fault may well be possessed by any batteries not designed and constructed with much care.

The standard "spilling test" was conducted by mounting in a testing machine 4 cells, selected at random from 50 submitted for test, and operating them for seven successive hours by shaking them back and forth in two general ways, designated as the "picking test" and the "shoveling test" from the services that the tests were intended to simulate.

Plate III, *A*, shows the testing machine with batteries assembled for the "picking test." Four cells were grouped in an upright position on a horizontal platform that was hinged on a vertical axis at a point 10 inches from the center of the group, and otherwise arranged so that it could be swung back and forth through a horizontal arc of 23° . Swinging the cell back and forth 72 times a minute for two hours constituted a "picking test," and two tests were given during the seven-hour period.

Plate III, *B*, shows the testing machine with batteries assembled for the "shoveling test." Four cells were grouped on their sides on a horizontal platform that was hinged on a horizontal axis at a point 40 inches below the center of the group and otherwise arranged so that the cells could be swung back and forth through a vertical arc of 21° . This operation repeated 48 times a minute for one hour constituted a "shoveling test," and three such tests were made during the seven-hour period.

Before the seven-hour test was begun the batteries were fully charged and allowed to stand on open circuit for one hour immediately preceding the "spilling test," which was made with the equipments completely assembled and with the bulbs burning. If any battery spilled one drop of electrolyte during the seven hours of test (three hours of "shoveling" and four hours of "picking") the venting system or devices had to be redesigned and retested.

LIGHT-PRODUCING CAPACITY.

The light-producing capacity of a lamp is the first essential of practicability and bears directly on safety.

CANDLEPOWER AND LIGHT FLUX.

The investigation of light-producing capacity requires the consideration not only of the amount of light produced but also of the character of its distribution, which includes the angle of the stream of light and the evenness of illumination of the surface upon which the stream is directed.

The light-producing capacity of a lamp is its capacity to produce a sufficient amount of properly distributed light. The determination of the amount requires the measurement of the candlepower and the area over which it acts, so that the total volume of light, as well as its intensity, may be known.

The bureau fixed as a minimum requirement of candlepower (intensity) and light flux (total light) the values obtained from a standard safety lamp.^a It was hoped, however, that the electric lamps submitted would considerably exceed the limits set, and that hope has been realized.

The standard tests for light-producing capacity were conducted as follows:

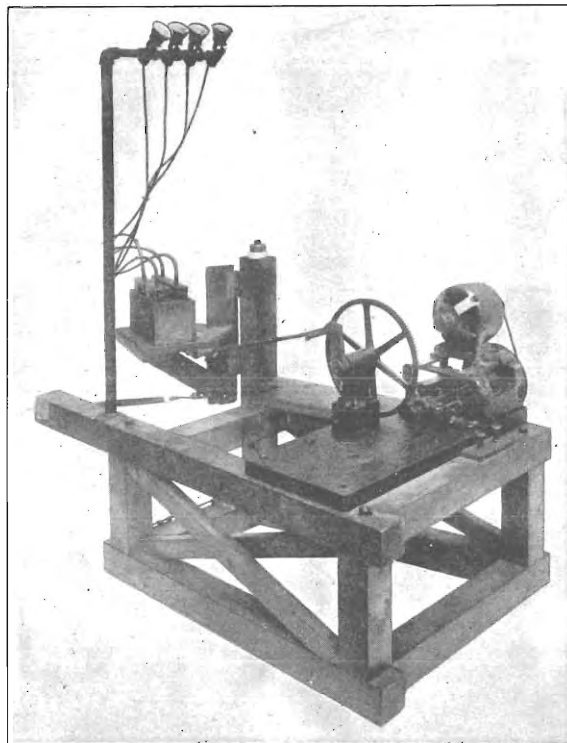
The candlepower and light flux of the lamps were measured by means of a Leeds & Northrup photometer using a Lummer-Brodhun contrast screen. The standard lamps were made and standardized by the National Lamp Works of the General Electric Co. All electrical instruments used for both standard and test lamps were compared at intervals with a Wolff potentiometer, and were compared before and after each test with a secondary standard used for no other purpose. Both the standard and the test lamps were operated from lead storage batteries.

The candlepower and light flux of a portable electric mine lamp depend on the bulb used, the condition of the battery, and the character and condition of the reflector. The candlepower value also depends on the method used to determine it; for instance, whether it is measured in one direction or whether it is measured in several and the average taken.

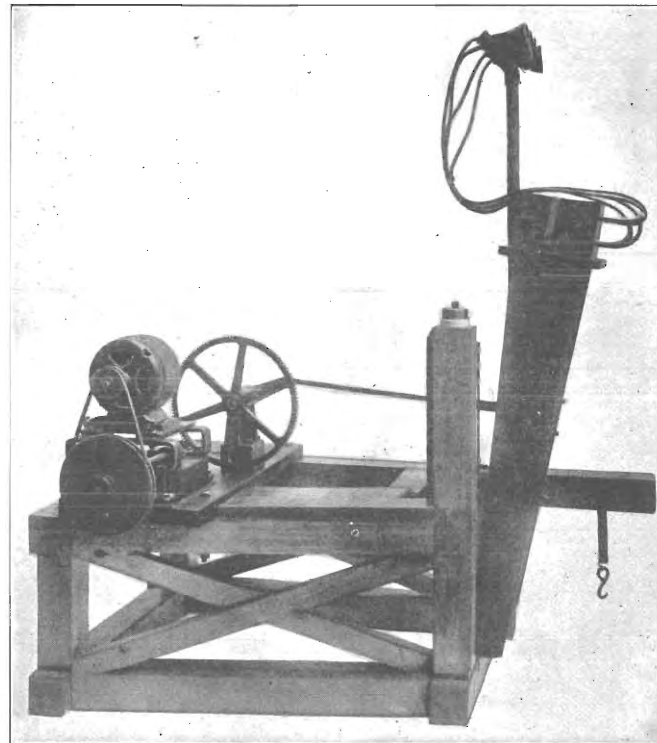
The bulb variable was eliminated by taking the average performance of 100 bulbs. The battery variable was eliminated by obtaining for 20 cells the average voltage after discharging under normal conditions for 1 hour and for 12 hours. The reflector variable was eliminated by averaging the performance of 6 reflectors.

It was considered that the best way to measure candlepower was to determine the average over the entire stream of light produced by the lamp, and this was done by mounting, as shown in Plate IV, a fully assembled headpiece so that it could be rotated rapidly around an axis that coincided with the axis of symmetry of the cone of light. The first reading on the photometer was then made directly in front of the rotating headpiece, which was swung through an arc of $2\frac{1}{2}^{\circ}$ for each successive reading until the light was no longer visible. By making the proper calculation from the data thus obtained, a very accurate average candlepower value was reached.

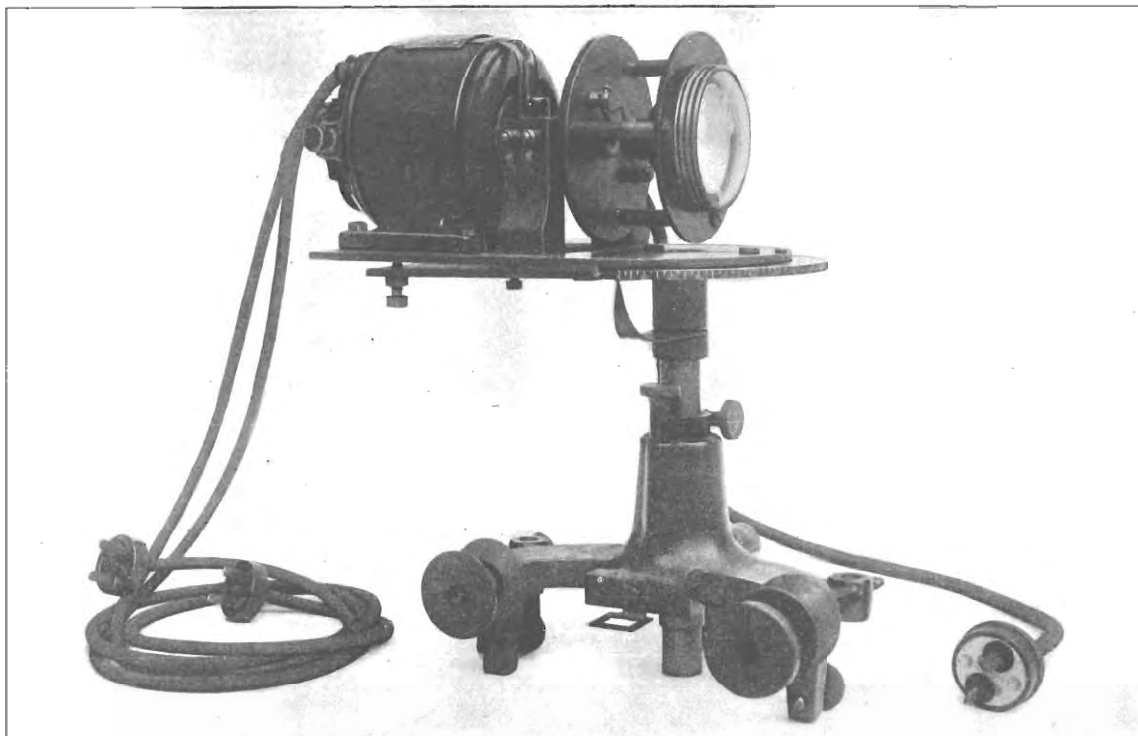
^a Clark, H. H., Permissible electric lamps for miners: Tech. Paper 75, 1914, p. 14.



A. MACHINE FOR TESTING THE NONSPILLING DEVICES OF MINE-LAMP BATTERIES, ASSEMBLED FOR "PICKING TEST."



B. MACHINE FOR TESTING THE NONSPILLING DEVICES OF MINE-LAMP BATTERIES, ASSEMBLED FOR "SHOVELING TEST."



DEVICE FOR ROTATING LAMP HEADPIECE WHEN MEASURING CANDLEPOWER.

Light from lamps that are carried on the cap is emitted in a cone of rays. The bureau adopted 130° as the minimum angle of this cone that would insure that the eyes of a man wearing the lamp would normally rest on a lighted surface.

The agreement of the lamps with this requirement was determined by means of the readings taken on the photometer while the candlepower was being measured.

The smoothness of distribution of the light was determined in two ways. The readings taken while measuring candlepower with the photometer were plotted as a curve, from which was calculated the corresponding values of illumination; also, the light from six equipments in succession was cast upon a white screen, and the presence or absence of shadows or of areas of contrasting illumination was observed directly.

TIME OF BURNING.

The time of burning on a single charge of the battery is a factor of the capacity of the lamp to produce light. A consideration of this quality is essential to the determination of practicability and has a remote bearing on safety.

The time of burning of an equipment is manifestly the time during which the equipment will produce with one charge of battery at least the minimum amount of light that the bureau prescribes. The standard time-of-burning test was conducted as follows: It was proved by test that a fairly constant relation existed between the candlepower of a bulb and the average candlepower of the stream of light that the bulb would produce when installed in the headpiece of a lamp. As a minimum value had been established for the average lamp candlepower, the determination of the minimum allowable bulb candlepower was a simple mathematical problem. Each of 100 bulbs was measured to determine the voltage that must be impressed upon the bulb to give the minimum bulb candlepower. This value of voltage was then referred to the lamp-battery discharge voltage curve, which was plotted between voltage and hours of discharge, to ascertain for how many hours the battery could be discharged before its voltage fell below the value that was required to give the minimum amount of light. Thus a time of burning was established for each of 100 bulbs and the average of the 100 determinations was taken as the time of burning of the equipment.

BULB CHARACTERISTICS.

The characteristics of the bulbs used with portable electric mine lamps are weighty factors in determining practicability and have a certain though less important bearing on safety. The bulb is the

complement of the battery, and if the bulb is not designed to work with the battery the results may be unsatisfactory. Unless the performance expected of the bulb is carefully defined and considered in the design of the bulb the resulting lack of uniformity will affect undesirably the reliability of performance.

The standard tests of bulbs were conducted as follows: The bulbs were measured for uniformity of current consumption, uniformity of candlepower, and length of life. From 1,000 bulbs submitted 100 were selected at random and burned for 12 hours to "season" them. Their current consumption and candlepower were then measured at a constant voltage and the value obtained for each bulb was compared with the average of the 100 bulbs to see if any exceeded the tolerance in uniformity prescribed by Schedule 6A.

The life of the bulbs was measured by operating 20 of them in standard mine-lamp equipments and 80 others in multiple on a large battery that had the same discharge voltage characteristics as the mine-lamp batteries. The bulbs tested on the mine-lamp batteries were burned 12 hours on a single charge of battery. The bulbs tested on the large battery were operated for various periods on a single charge, but the starting and stopping voltage for each discharge was made the same as for the mine-lamp batteries, thus insuring uniformity of test conditions.

LIFE OF BATTERIES.

The life of batteries is manifestly of considerable importance in the determination of practicability because it bears directly on cost of upkeep.

The life of a properly designed and constructed mine-lamp battery should be not less than three hundred 12-hour discharges, and the makers of some mine-lamp equipments guarantee twice this life. It was not practicable for the bureau to make tests of this duration, but the behavior of the batteries was carefully observed while the life test of bulbs was being conducted, and if the batteries exhibited any tendency to early deterioration, or if they required excessive care and attention, they were not approved.

LIFE OF LAMP CORDS.

The life of the lamp cords has such a bearing on practicability that at one time it was almost the limiting feature. Cords of short or uncertain life not only increase the cost of upkeep, but also affect adversely the reliability of the equipment by causing unexpected interruptions. Early in the development of electric lamps for wearing on a miner's cap it became manifest that the design of the cord

connecting the battery to the headpiece presented a problem of some difficulty. Long after other weak points of the equipment had been eliminated the cord continued to give trouble, until finally it came to be regarded as the weakest part of a mine-lamp equipment. The bureau therefore undertook to assist in the development of a satisfactory cord, with the gratifying results reported in pages 19 to 22, where is set forth the method of conducting the standard tests of cords.

MECHANICAL AND ELECTRICAL CHARACTERISTICS.

The mechanical and electrical characteristics of an equipment determine the degree of practicability and safety of the equipment, as they bear on continuity of service, the likelihood of sudden interruptions, and the cost of upkeep.

Examination for these characteristics involves consideration of the strength of the various parts, their ability to function under continuous service, and the extent to which they require unusual attention or expert care in operation and maintenance.

The standard method of investigating the mechanical and electrical characteristics of the lamps was as follows: The mechanical strength of the lamps was determined by test and by inspection. Hand lamps and the headpieces of cap lamps were tested by dropping 10 times on a concrete floor from a height of 6 feet. If a lamp or a headpiece was materially deformed as the result of these tests, changes in construction were required. The test of the complete cap-lamp equipment was made with four batteries, each of which, unless broken previously, was dropped 20 times upon a wooden floor from a height of 3 feet. If any battery developed a leak before it had been dropped 6 times, or if the four batteries could not be dropped an average of 10 times without developing a leak, the jar of the battery had to be made more substantial.* Then the tests were repeated.

The consideration of the mechanical and electrical features of a lamp was begun as soon as the lamp was submitted and was completed only when the lamp was finally accepted. The long and varied experience of the bureau's engineers with the operation and testing of lamps has provided them with considerable information which was placed at the service of mine-lamp makers in the form of constructive criticism of the details of construction. Especial attention was given to directing the development so as to insure uninterrupted service with a minimum of repairs, adjustments, or replacements of parts. If a lamp when submitted was manifestly weak in any mechanical feature the bureau required that the defect be remedied before the formal investigation of the lamp was begun. If mechanical or electrical weaknesses were discovered during the course of the

investigation the lamp manufacturer was required to strengthen the weak part before the approval was issued. After the completion of all the tests two equipments complete with all modifications were examined in detail and final changes were required if essential, or recommended if merely desirable.

DEFICIENCIES REMEDIED.

The equipments as first submitted to the bureau were deficient in some or all of the following features: Safety device, angle of light stream, distribution of light, life and uniformity of bulbs, cord clamps, strength of cord armor, life of cords, suitable means for locking the battery casings, and workmanship. These deficiencies have all been overcome to a greater or less extent, and most of them completely, in the equipments that have been approved by the bureau.

SAFETY DEVICE.

Each manufacturer developed his own safety device, but the bureau has been largely instrumental in perfecting, as described below, the other features mentioned.

ANGLE OF LIGHT STREAM.

From the outset of the investigation the bureau engineers emphasized the need of a wide angle of light stream so that the eyes of the lamp user may normally encounter no unlighted surfaces. If the angle of the light stream is the same as a man's angle of vision the lamp produces the effect of complete illumination with its attendant freedom of movement. Experiment showed that a light stream having an angle of 130° produced very nearly the desired effect and that value was adopted by the bureau as a minimum requirement. The angle of the light stream of four of the seven types of lamps that have been approved by the bureau was increased to 130° from values as low as 85° in one instance.

DISTRIBUTION OF LIGHT.

The amount of light produced by any of the approved portable electric mine lamps is not large, the most powerful producing about 5.3 lumens (a good flame safety-lamp produces about 3 lumens), but it is adequate if distributed evenly over the surface illuminated. Uneven distribution not only tires the eyes, but is inefficient, because light from the brighter parts causes the pupil of the eye to contract so that the parts more faintly illuminated can not be clearly seen.

Highly polished reflectors are more efficient than dull surfaces but the distribution of light is as a rule decidedly uneven and the sur-

face illuminated is covered with sharply contrasting areas of bright and faint illumination. In order to avoid such sharp contrasts, reflecting surfaces that diffused the light had to be used. Also the design of the shape of the reflectors required considerable skill and care in order to distribute the light evenly over the surface and prevent concentration of light in the center of the light stream. Only one of the lamps as submitted met the requirements for distribution of light (see p. 47) and various changes were necessary in the others. Plates V and VI show two instances where the distribution, and in one instance the angle of light, was improved by the manufacturer at the bureau's request.

BULBS.

One of the most important parts of the lamp equipment is the bulb, which converts into light the energy supplied by the battery. Evidently the bulb should operate at the highest practicable efficiency. The efficiency of a bulb increases with the operating temperature of the filament but unfortunately the life of a bulb decreases as the operating temperature rises so that an increase in efficiency is unavoidably accompanied by a decrease in life.

Therefore, to produce a bulb for mine-lamp service in which the efficiency and the life of the bulb have each received proper consideration required more care and thought than had been given before to the design of miniature bulbs. Uniformity in bulb performance is always a desirable thing, but is especially desirable if the bulb is to be properly designed for the equipment with which it is used. That is to say, if the bulb is designed to give the maximum possible efficiency consistent with the life requirements a departure from this design can not fail to give too short a life or too low an efficiency.

At the outset of its investigation the bureau found that the types of miniature lamp bulbs on the market were unsatisfactory for use in mine lamps and for months the lamp manufacturers could not obtain American bulbs that the bureau could approve. However, the bureau was successful in arousing the interest of bulb manufacturers in making bulbs better suited to mine-lamp service and with their cooperation bulbs suitable for this service have been designed and manufacturing methods have been developed that already insure a gratifying degree of uniformity and promise to accomplish even better results soon.

CORD AND ACCESSORIES.

Long after the remainder of the equipment was fairly well developed the cord that connects the battery and the bulb was still giving trouble of a most trying sort by developing open circuits,

partial or complete, often unexpectedly and always after a comparatively short term of service.

Part of this trouble was caused by the lack of means for fastening the cord to the shell of the battery cover and the headpiece in order to relieve the electrical connections of the strains that the cord must receive in service. Such a means of fastening was one of the first requirements of the bureau and all approved lamps have an adequate device for clamping the cord.

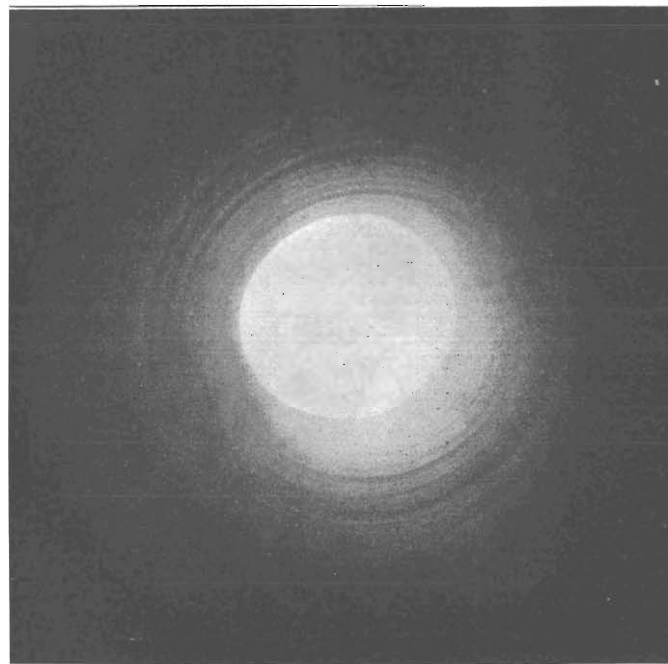
Trouble with the cords was due in even greater degree to inadequate reinforcement where the cords left the battery casing and where they entered the headpiece. Situations of this sort have always been difficult for flexible electric conductors and the electric mine lamp has been no exception. The earlier types of armor were so weak that often they were outlasted by the cord which they were designed to protect. The lamp manufacturers, in cooperation with the bureau, have now developed protective armors that give satisfactory service, although the design of some cords can and no doubt will be improved.

The need for better cords as demonstrated by actual service in mines became so acute that, as stated earlier in this report, the bureau endeavored to assist the development of the lamp by undertaking, with the cooperation of the manufacturers of insulated electric conductors, the development of a suitable mine-lamp cord. Letters were sent to various wire and cable manufacturers stating that the bureau would make, without charge, comparative tests of such cords as were submitted, preference being given to cords made in accordance with the bureau's suggestions, which were outlined in a short memorandum that was sent to each manufacturer addressed. The following companies expressed a willingness to submit for test, without charge to the bureau, samples of flexible cord designed for mine-lamp service: General Electric Co., John A. Roebling's Sons Co., Kerite Insulated Wire & Cable Co., Okonite Co., Simplex Wire & Cable Co., and Standard Underground Cable Co.

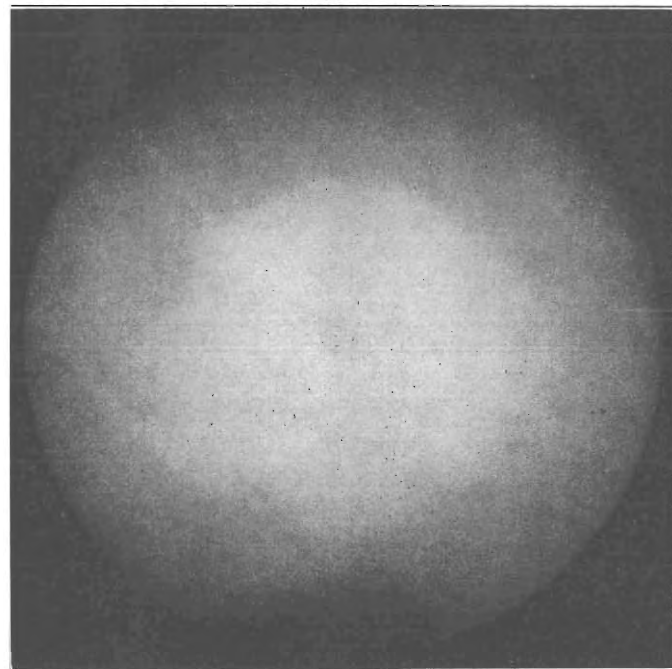
Eighteen types of cord were submitted and tested and a report of the results was sent to each manufacturer cooperating and to each manufacturer of portable electric mine lamps.

CORD-TEST PROCEDURE.

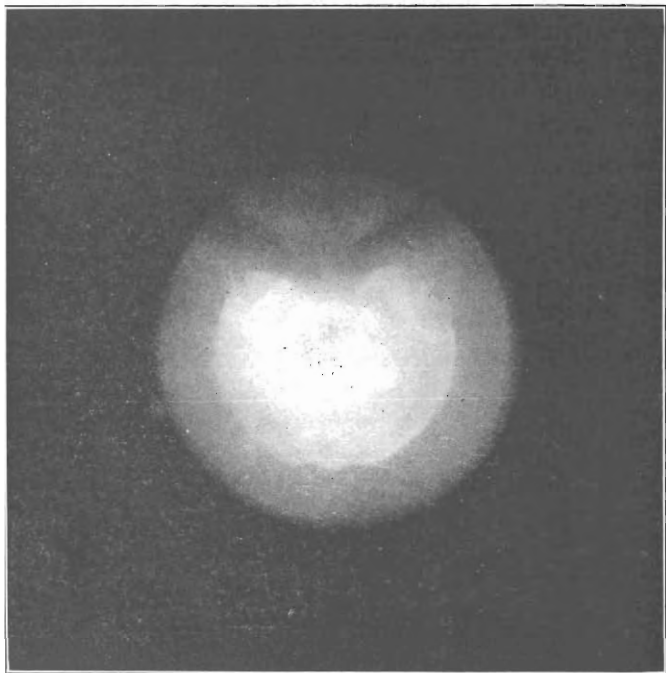
Portable electric mine-lamp cords are destroyed by the switching back and forth while attached to the body of a working miner. In the past this switching has caused the wires to break before the insulation was even damaged. The test to which these cords were submitted by the bureau imitated the switching of the cords in service, but the amplitude, speed, and frequency of the switching was



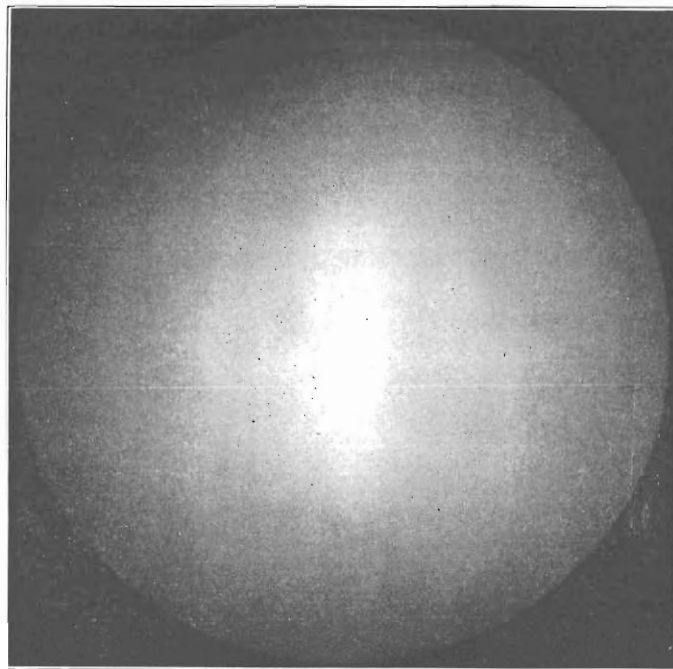
A. CIRCLE OF LIGHT CAST BY LAMP "X" AS SUBMITTED FOR TEST.



B. CIRCLE OF LIGHT CAST BY LAMP "X" AS APPROVED BY BUREAU OF MINES.



A. CIRCLE OF LIGHT CAST BY LAMP "Y" AS SUBMITTED FOR TEST.



B. CIRCLE OF LIGHT CAST BY LAMP "Y" AS APPROVED BY BUREAU OF MINES.

exaggerated in order to hasten the test results and to provide a factor of safety.

DESCRIPTION OF CORD-TESTING DEVICE.

The testing device (Pl. VII) consisted of a rectangular frame that was swung back and forth by a motor, the cords being so mounted on this frame that they slatted as it oscillated. The frame was hung in a vertical position from a horizontal shaft that passed along its upper edge. Ten battery covers were mounted on the lower edge of the frame, their tops being 43 inches below the center of the shaft about which the frame swung. One end of each cord was fastened in the battery cover by the means provided and the other end was fastened to the frame at a point 24 inches above the battery cover. The length of the cord between fastenings was 36 inches, which provided enough slack for the slatting of a cord when the frame oscillated.

The frame was swung back and forth 92 times a minute through a vertical angle of $50^{\circ} 30'$, causing the cords to slat vigorously. Each cord was moved to and fro between horizontal stationary guide bars made of oak, sandpapered and shellacked, and spaced $2\frac{1}{2}$ inches apart. These bars, which were placed about half-way between the points at which the cord was fastened, had an abrading action on the outer covering of the cord, although the abrasion was decidedly slow. An automatic counter was connected to the frame for registering the number of oscillations.

ELECTRICAL CONNECTIONS.

Ten cords were tested simultaneously, the cords being connected in series with each other and with a relay that stopped the motor automatically when the test was completed. The motor was operated until the cord system open-circuited or until it increased in resistance to 10 times the original value. Poor cords were tested until the circuit opened, good cords until their resistance increased 10 times. When the motor was stopped the following method was used to determine which of the 10 cords had developed excessive resistance or an open circuit.

Each cord as connected for test was shunted across a miniature incandescent bulb and all cords were connected in series. Means were provided for switching into this series a miniature bulb shunted across a resistance of 10 times the normal resistance of one cord. This bulb, with the resistance, was called the "comparator." When current was passed through the comparator and the 10 cords in series the shunted lamps glowed in proportion to the resistance across which they were shunted. Therefore the bulb of any cord whose

resistance had increased to 10 times the normal glowed as brightly as the comparator bulb, and conversely any cord whose bulb was less brilliant than the comparator bulb had not reached the maximum resistance allowable.

RESULTS OF CORD TEST.

When the investigation began the best lamp cord then tested in the laboratory of the bureau averaged about 30,000 operations. During the cooperative work with the manufacturers of electric conductors there were developed two cords that gave more than 100,000 operations on the average, three that gave more than 200,000 operations, and one that gave over 1,000,000. It is therefore believed that the problem of the mine-lamp cord has been solved.

LAMPS APPROVED AND DESCRIPTION OF TESTS.

The lamps that were approved by the bureau and the tests of these lamps are described in the following pages. All tests reported here were made under the provisions of Schedule 6A, which is given in full on pages 45 to 53, and unless stated to the contrary were the standard tests described previously in this paper.

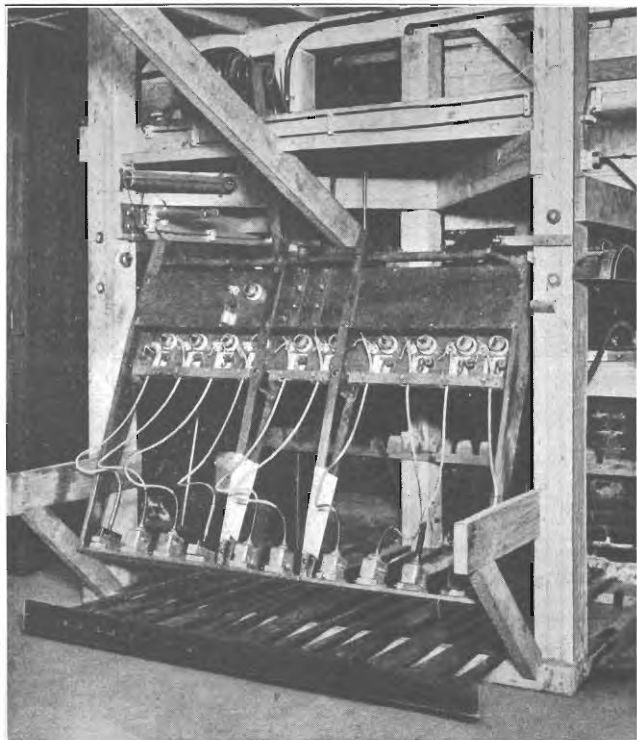
EDISON LAMP, APPROVAL NO. 10.

The Edison lamp, submitted by the Edison Storage Battery Co., of Orange, N. J., is a cap lamp operated by two cells of alkaline battery. The lamp weighs about four pounds and has a capacity of 35 to 44 lumen-hours (depending on the brand of bulb used) for a 12-hour shift. It has a snap lock opened with a key. Detailed specifications for this lamp are given in Table 1 (p. 44). The assembled equipment is shown in Plate VIII, and its component parts in Plate IX.

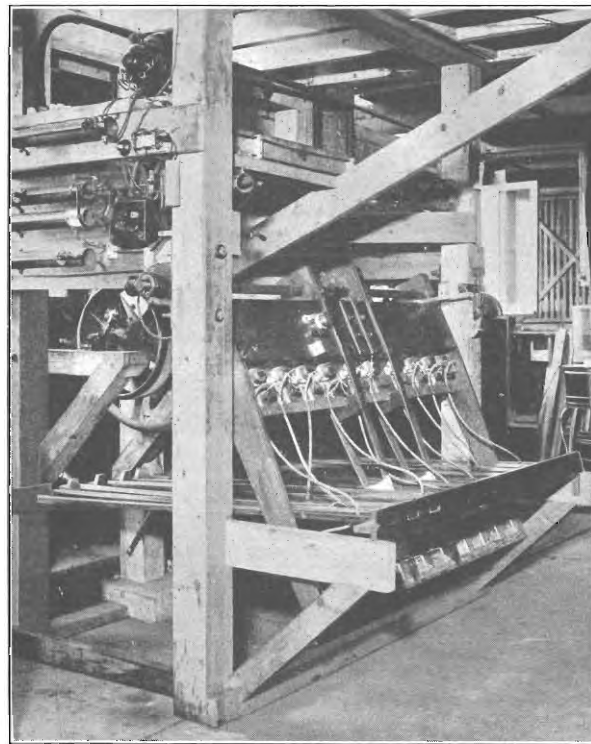
The lamp was tested in accordance with the requirements of Schedule 6A, and after several changes in design and construction had been made was approved February 24, 1915, for safety and for practicability and efficiency in general service (approval No. 10).

GAS-IGNITION TESTS.

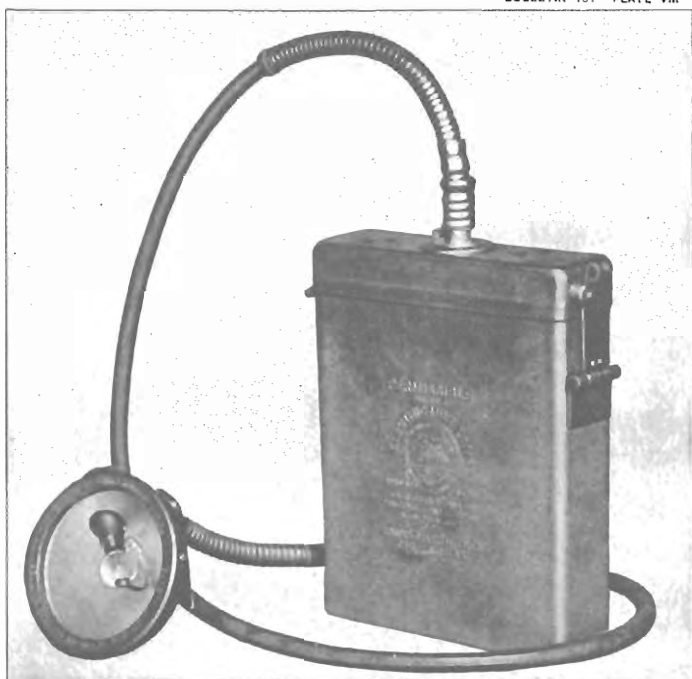
The device that is designed to prevent gas ignition is shown in figure 1. It consists of a spring *a* that holds the bulb in circuit as long as the bulb is intact, but allows it to fall out of circuit if the bulb glass is broken. The release from circuit is assisted by the spring *b* that presses against the center contact *c* in the base of the bulb. The first tests made of the lamp indicated the desirability of certain changes in the design of the safety device, and after these were made the tests were repeated, with satisfactory results.



A. MACHINE FOR TESTING MINE-LAMP CORDS, WITH GUIDES REMOVED TO SHOW AMOUNT OF SLACK GIVEN CORDS AND METHOD OF MOUNTING.



B. CORD-TESTING MACHINE WITH GUIDES PLACED IN POSITION.



EDISON LAMP, APPROVAL NO. 10.

The maximum current that could be obtained by short-circuiting the lamp battery was determined by the standard test to be less than 30 amperes, which is well below the maximum test requirement for batteries of this type.

TENDENCY TO UNEXPECTED EXTINCTION.

As first submitted for test the lamp had several unnecessary contacts and connections between the battery and the bulb, and the

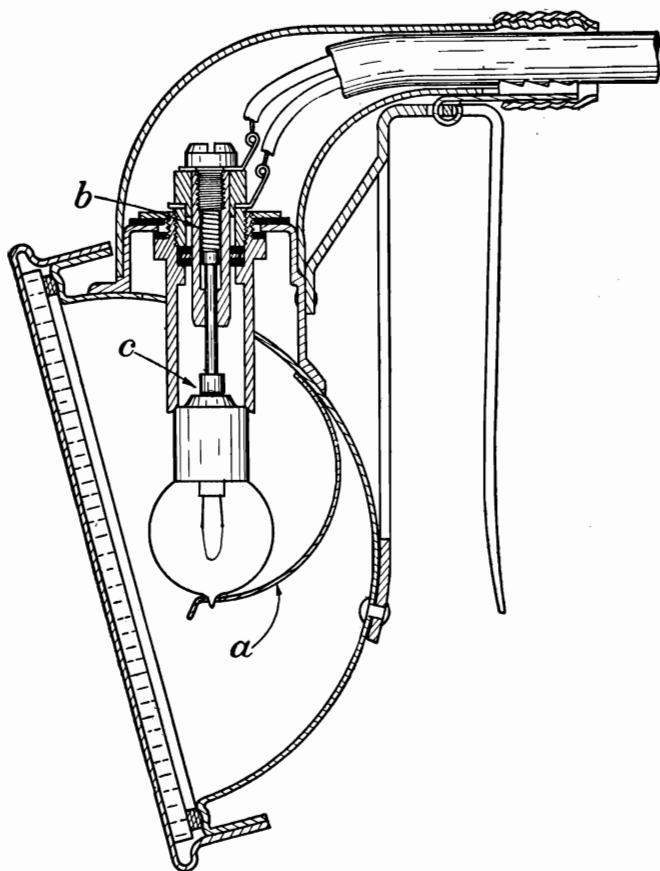


FIGURE 1.—Sectional view of headpiece of Edison lamp, showing principle of safety devices.

methods of making connections were not altogether satisfactory. These contacts were the only probable source of unexpected extinction, for the battery had sufficient capacity and was reliable in action, and it had been proven by the standard tests that the safety devices were not so delicate as to operate prematurely. At the bureau's request the manufacturer eliminated some of the contacts and improved the character of some of the connections, thus eliminating the tendency to unexpected extinction.

SPILLING OF ELECTROLYTE.

The batteries passed the standard tests without spilling a drop of electrolyte.

LIGHT-PRODUCING CAPACITY.

AMOUNT OF LIGHT.

Three different bulbs having different characteristics were approved for use with this lamp. The amount of light that each produced is shown in the table following.

Amount of light produced by the Edison mine lamp, approval No. 10, using various bulbs approved for use with this lamp.

	Bulb symbol.		
	26-V. ^a	Edison BM-10. ^b	National BM-10. ^c
Average candlepower after burning 1 hour.....	1.19	1.04	1.21
Average candlepower after burning 12 hours.....	0.83	0.59	0.71
Total lumens after burning 1 hour.....	4.32	3.76	4.39
Total lumens after burning 12 hours.....	3.01	2.13	2.58

^a Made by the Independent Lamp & Wire Co., New York, N. Y.

^b Made by the Edison Lamp Works of the General Electric Co., Harrison, N. J.

^c Made by the National Lamp Works of the General Electric Co., Cleveland, Ohio.

DISTRIBUTION OF LIGHT.

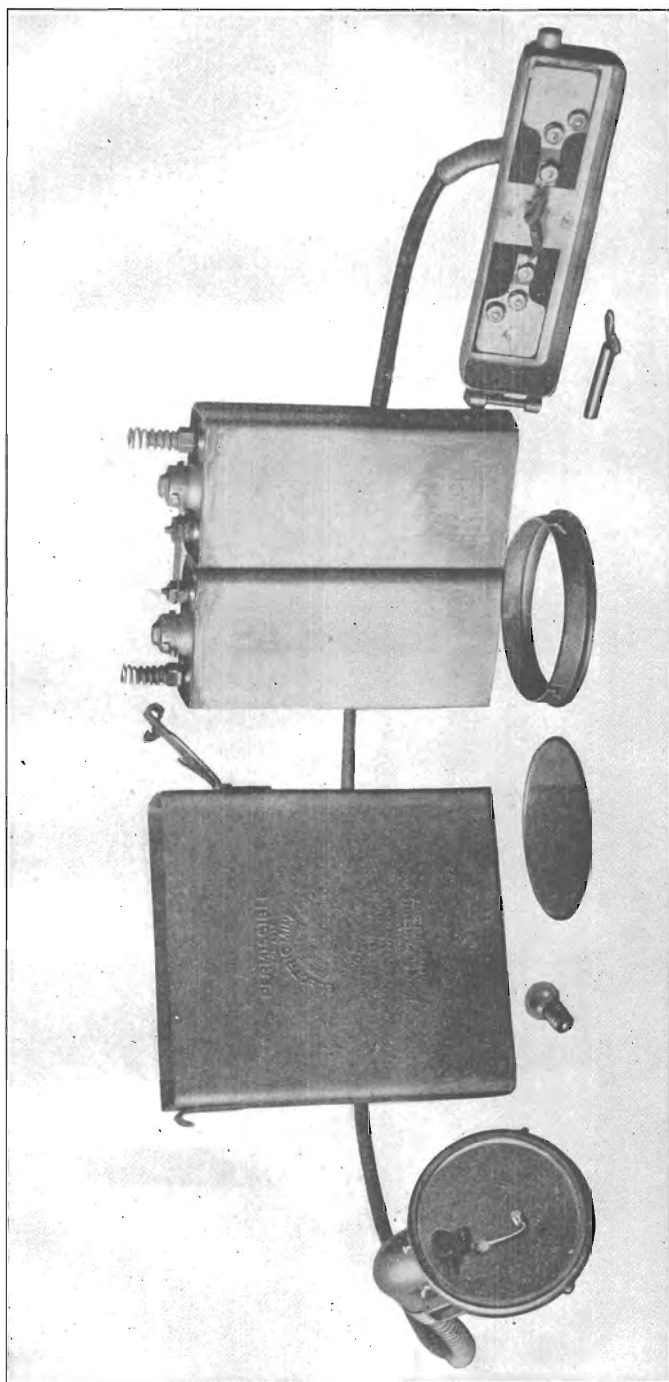
The distribution of light from the headpiece first submitted with the Edison lamp was not smooth and uniform and the angle of the light stream was much too narrow. The manufacturers, therefore, completely remodeled the headpiece. The distribution from the remodeled headpiece was measured in the standard way and was found to meet the test requirements so nearly that it could be approved. The reflector is covered with the so-called "cleanezy" finish and is not detachable.

TIME OF BURNING.

It was determined by the standard test that the lamp would burn on the average about 16 hours on one charge of battery before the average candlepower of the light stream fell below 0.4 (the minimum test requirement).

BULB CHARACTERISTICS.

Eight lots of different bulbs, consisting of 1,000 bulbs each, were submitted for test in connection with this lamp. Three bulbs were approved—the symbol 26-V bulbs, made by the Independent Lamp & Wire Co.; the symbol BM-10 bulbs, made by the Edison Lamp



PRINCIPAL PARTS OF EDISON LAMP.

Works of the General Electric Co.; and the symbol BM-10 bulbs made by the National Lamp Works of the General Electric Co. Each lot of these bulbs burned in the standard test for more than 200 hours, and if the bulbs had been burned to extinction or until their candlepower had fallen below the test requirements the average life would doubtless have been much longer than 200 hours.

The characteristics of the various lots of bulbs approved by the bureau for use with this lamp are given in the table following:

Characteristics of bulbs approved for use with the Edison mine lamp, approval No. 10.

	Bulb symbol.		
	26-V.	Edison BM-10.	National BM-10.
Percentage of bulbs lasting less than 150 hours ^a	2.0	1.0	1.0
Broadside candlepower ^b after burning 1 hour ^c	0.821	0.668	0.805
Current consumption after burning 1 hour (amperes) ^c	0.397	0.384	0.375
Percentage of bulbs that were more than 30 per cent below the average candlepower.....	0.0	0.0	0.0
Percentage of bulbs that consumed 6 per cent more current than the average.....	2.0	0.0	0.0

^a Minimum test requirement for bulbs used with alkaline-battery lamps.

^b Candlepower measured with the filament loop broadside to the photometer screen.

^c These measurements were made at the average voltage manifested by the lamp battery after it had been discharged for 1 hour.

The bulbs finally approved were much superior to the bulbs first submitted for test, and marked a distinct advance in the design and methods of manufacture of miniature bulbs for mine-lamp service.

LIFE OF BATTERIES.

The manufacturers of the Edison lamp guarantee their batteries for two years; therefore it is manifest that the bureau could not make very searching tests with respect to the life of the lamp in the comparatively brief time that is usually required to make a complete investigation of a portable electric mine lamp.

The batteries gave the best of service during nearly 600 hours of actual discharge covering a period of more than seven months. Reports from the field covering more than a year of actual service of these batteries indicate that the bureau's approval of battery life was justified.

LIFE OF CORDS.

Considerable trouble was experienced in obtaining a satisfactory cord for the Edison lamp, and six different types were tested before a cord of acceptable durability was found. Part of the cord trouble was caused by weak armor, which the manufacturer has replaced with armor of a more suitable design.

MECHANICAL AND ELECTRICAL CHARACTERISTICS.

The mechanical strength of the lamp was tested by dropping the headpiece 15 times on a concrete floor from a height of 6 feet. The

tests indicated that the construction of the headpiece was not sufficiently substantial, and it was reconstructed of heavier material.

The battery and the battery casing were dropped 10 times upon a wooden floor from a height of 3 feet. The equipment passed this test satisfactorily. In subsequent tests of other lamps this test was modified so as to average the performance of several batteries, but the severity of the test was not diminished.

During the tests and since the formal approval of the lamp numerous changes in construction were made by the manufacturers at the suggestion of the bureau engineers and as the result of experience under service conditions in mines. These changes have tended to increase durability, reliability, and the convenience of operation and maintenance.

The construction of the headpiece has been made much more substantial, the strength of the battery casing has been increased, an efficient means has been developed for clamping the cord in the headpiece and battery casing, and the cord armor has been made more substantial. A more convenient lock has been designed and the design of the vent plugs has been changed to make them more reliable and much easier to manipulate.

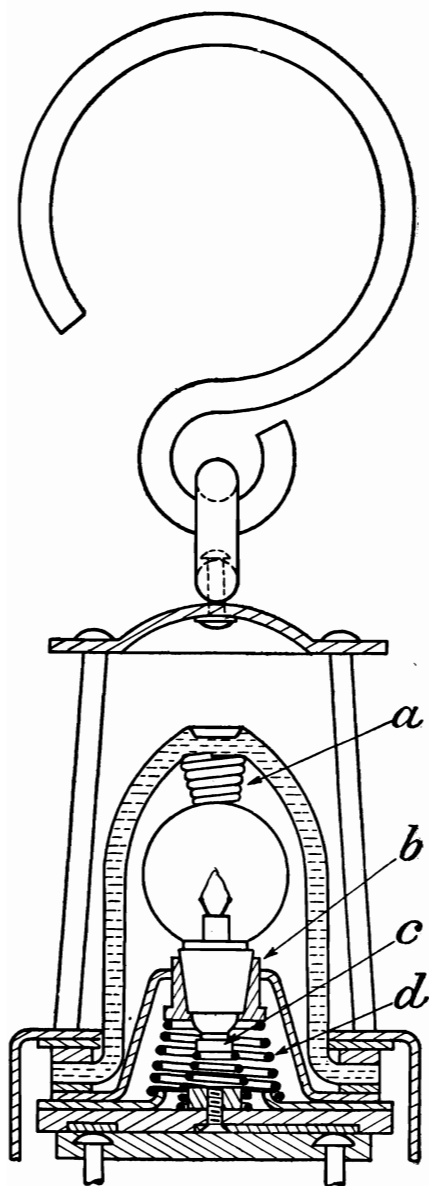


FIGURE 2.—Sectional view of upper part of Concordia hand lamp, showing principle of safety devices.

As the lamp is now constructed it is durable and reliable and has given satisfactory service in many mines where it has been in use

for periods ranging from a few months to nearly a year and a half.

The lamp was approved with recommendations by the bureau for (1) improvement in design of the filling plug and (2) improvement in the gasket that cushions the outer glass of the headpiece. The bureau's recommendations in respect to the filling plug have been adopted.

MANLITE LAMP APPROVAL WITHDRAWN.

Approval No. 11, which was granted to the Manlite lamp made by the Mannesmann Light Company of America, was rescinded for cause on April 23, 1917.

CONCORDIA HAND LAMP, APPROVAL NO. 12.

The first lamp submitted by the Concordia Safety Lamp Co., of Pittsburgh, Pa., is a hand lamp operated by a single cell of lead battery. The lamp weighs about $5\frac{1}{2}$ pounds, and has a capacity of about 73 lumen-hours for a 12-hour shift. It is provided with a snap lock operated by an electromagnet. Detailed specifications are given in Table 1 (p. 44). The assembled equipment is shown in Plate X, A, and its component parts in Plate XI.

The Concordia hand lamp was tested in accordance with the requirements of Schedule 6A and after several changes in construction had been made was approved on July 26, 1915, for safety and for practicability and efficiency in general service (approval No. 12).

GAS-IGNITION TESTS.

The device that is designed to prevent gas ignition is shown in figure 2. A spiral spring *a* mounted between the bulb and the glass dome that surrounds it presses the bulb firmly against its contacts *b* and *c*, at the same time compressing the spring *d*. If either the bulb or the glass dome is broken the spring *d* pushes the bulb upward and away from the center contact *c*, thus interrupting the circuit. The effectiveness of this device was tested in the standard manner with satisfactory results.

The maximum current that could be obtained by short-circuiting the Concordia hand lamp battery was determined by the standard test to be about 61.6 amperes, which is a safe value for batteries of this type.

TENDENCY TO UNEXPECTED EXTINCTION.

The tendency to unexpected extinction was tested in the standard way. The lamp proved satisfactory.

SPILLING OF ELECTROLYTE.

The batteries were tested in the standard manner except that, because they were used with hand lamps, they were not given the "shoveling test," but instead were placed on their sides during the interval usually devoted to shoveling. The batteries passed these tests without spilling a drop of electrolyte.

LIGHT-PRODUCING CAPACITY.

AMOUNT OF LIGHT.

Only one type of bulb (symbol Osram 08510) was tested in connection with the Concordia hand lamp. The amount of light produced is shown in the table following:

Amount of light produced by the Concordia hand lamp, approval No. 12.

Average candlepower after burning 1 hour.....	0.74
Average candlepower after burning 12 hours.....	0.57
Total lumens after burning 1 hour.....	6.92
Total lumens after burning 12 hours.....	5.36

DISTRIBUTION OF LIGHT.

The Concordia hand lamp does not use a reflector. The Bureau of Mines does not investigate the distribution of light from lamps not provided with a reflector.

TIME OF BURNING.

The standard tests showed that the lamp would burn, on an average, about 17 hours on one charge of battery before the average candlepower of the light stream fell below 0.4 (the minimum test requirement of the bureau).

BULB CHARACTERISTICS.

The first lot of 1,000 bulbs submitted in connection with this lamp met the test requirements. These bulbs were identified by the symbol Osram 08510 and were made by the AuerGesellschaft, of Berlin, Germany. This lot of bulbs burned in the standard test for more than 300 hours (the minimum test requirement for bulbs used with lead battery), and undoubtedly would have averaged much more than this figure if the bulbs had been burned to extinction or until their candlepower had fallen below the test requirement.

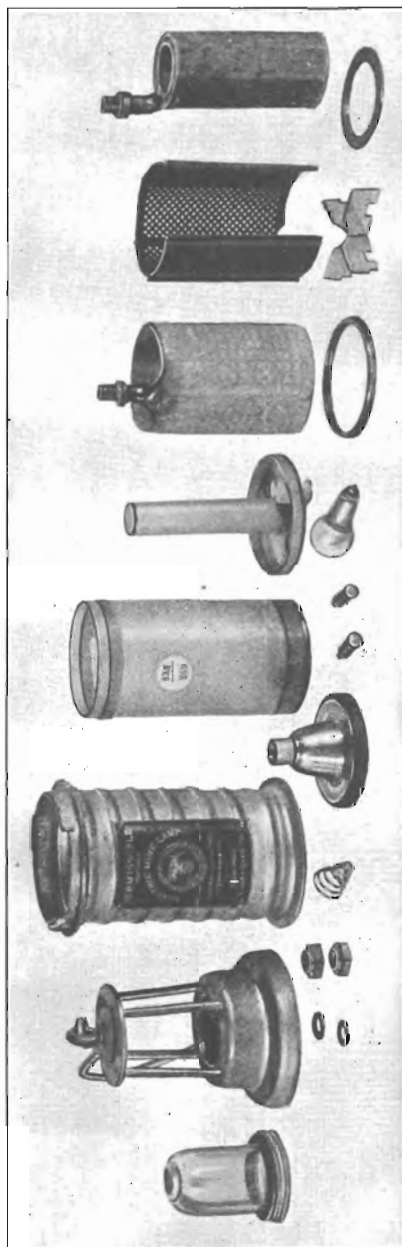
The table following gives the characteristics of the Osram 08510 bulbs:



A. CONCORDIA HAND LAMP, APPROVAL NO. 12.



B. WICO LAMP, APPROVAL NO. 14.



PRINCIPAL PARTS OF CONCORDIA HAND LAMP.

Characteristics of Osram 08510 bulbs for Concordia hand lamp.

Percentage of bulbs lasting less than 250 hours ^a -----	0.0
Broadside candlepower ^b after burning one hour ^c -----	0.996
Current consumption after burning one hour, ^c amperes-----	0.862
Percentage of bulbs that consumed 6 per cent more current than the average-----	0.0
Percentage of bulbs that were more than 30 per cent below the average candlepower-----	0.0

LIFE OF BATTERIES.

The Concordia hand-lamp battery as first submitted for test did not meet requirements and the manufacturers remodeled it in accordance with the suggestions of the Bureau of Mines engineers. After the battery had been remodelled it was retested and those tested gave excellent service during the comparatively brief time they were on test and gave no evidence of early deterioration.

MECHANICAL AND ELECTRICAL CHARACTERISTICS.

The mechanical strength of the Concordia hand lamp was tested in the standard way. The batteries failed to pass the first series of tests on account of faulty construction, but a set of properly constructed batteries passed the subsequent tests.

Few changes in construction were made in this lamp, as it came to the bureau thoroughly developed. The principal change was the introduction of a hard-rubber separator between the positive and negative plates of the battery and the substitution of a molded compound base for the mounting of the contacts in the top half of the lamp.

The lamp in the form that was approved is durable and reliable. It was approved with recommendations by the Bureau of Mines for (1) the exercise of greater care in the sealing of battery jars, and (2) the use of a tougher material for the base for mounting the contacts in the upper part. The writer has not been advised that these recommendations have been adopted.

GENERAL ELECTRIC LAMP, APPROVALS NOS. 13 AND 13A.

The lamp submitted by the General Electric Co., of Schenectady, N. Y., is a cap lamp operated by a single cell of lead battery. Two forms of this type of lamp were submitted. The Form C lamp had a sheet steel casing and the Form D lamp has a cast aluminum

^a The minimum test requirement for bulbs used with a lead-battery lamp.

^b Candlepower measured with the filament loop broadside to the photometer screen.

^c These measurements were made at the average voltage manifested by the lamp battery after it had been discharging for one hour.

casing; in all other details they were identical. The Form C lamp weighs 4.41 pounds and the Form D lamp weighs 4.74 pounds. Both have a capacity of 36.6 lumen-hours for a 12-hour shift, and each is provided with a snap lock opened with a key. Detailed specifications of the lamps are given in Table 1. The assembled equipment and the component parts of the Form C lamp are shown in Plates XII, A, and XIII, and those of the Form D lamp are shown in Plates XII, B, and XIV.

Each of the two forms of this lamp was tested, and after several changes in construction had been made both forms were approved

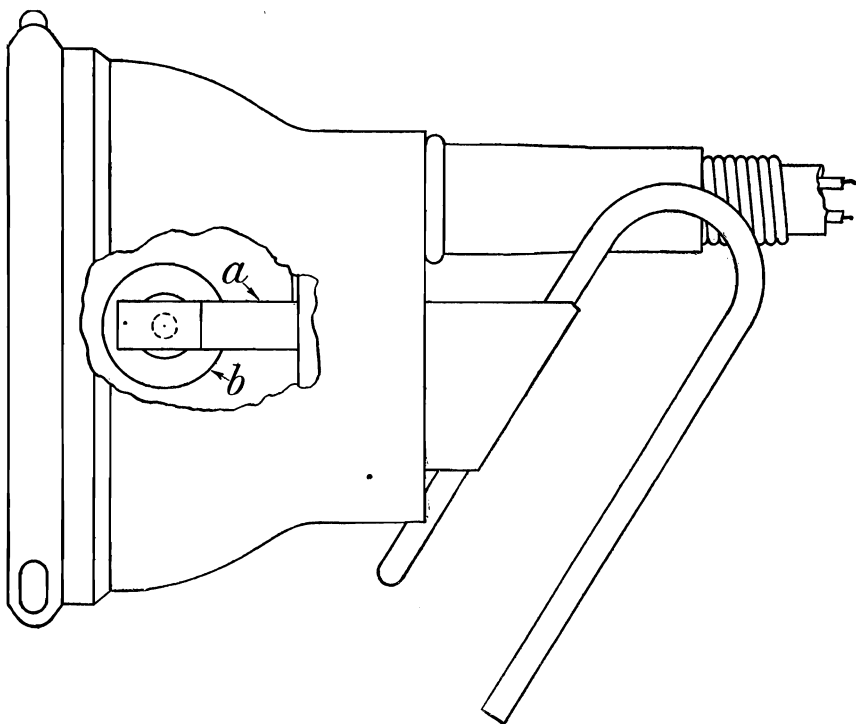
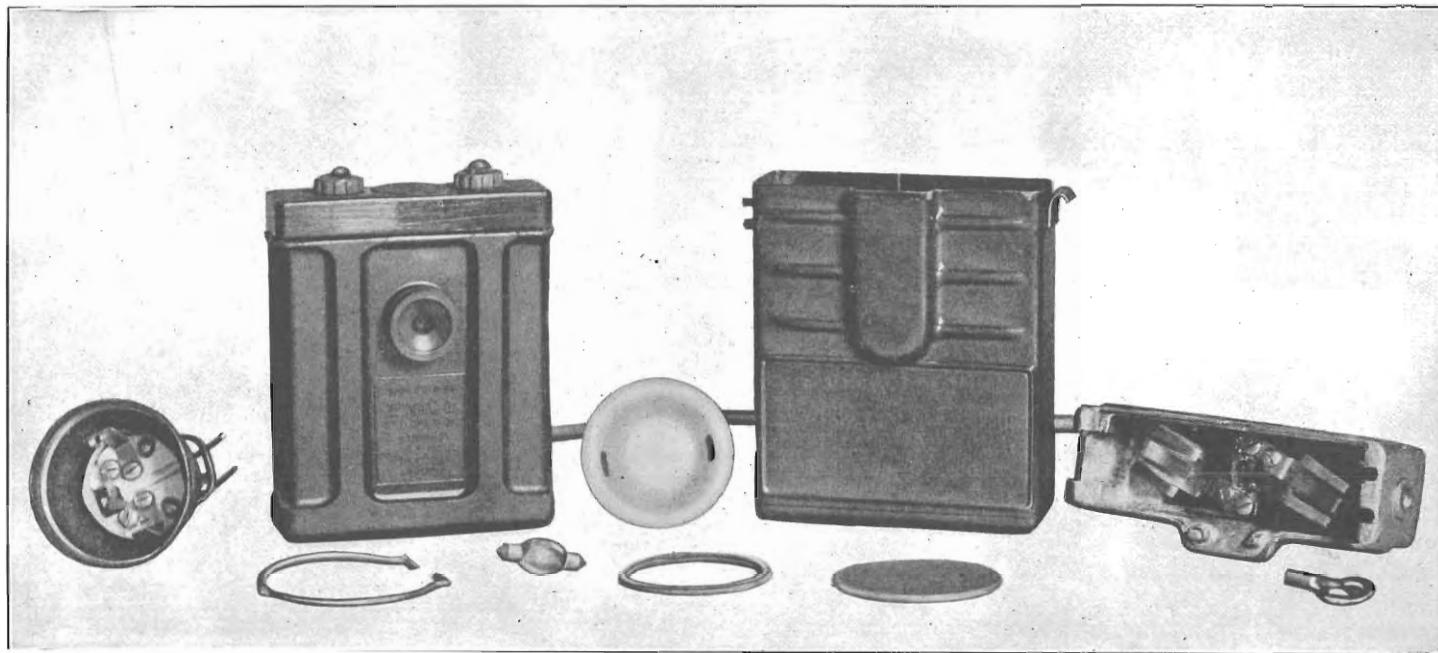


FIGURE 3.—Headpiece of General Electric lamp, side view.

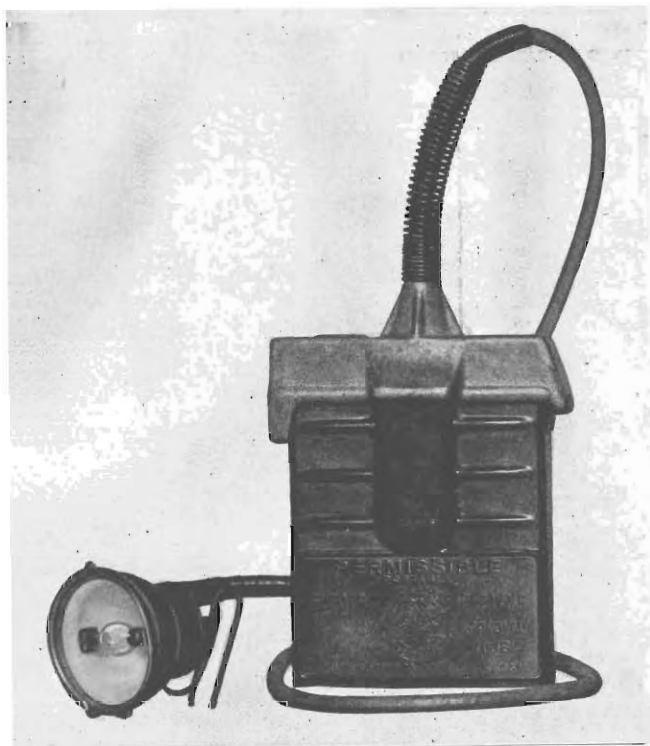
by the Bureau of Mines on July 11, 1916, for safety and for practicability and efficiency in general service (approvals Nos. 13 and 13A).

GAS-IGNITION TESTS.

The device that is designed to prevent gas ignition is shown in figures 3 and 4. The bulb *b* has a contact at each end and is held in position between the two springs *aa*. When the bulb is broken it falls out of contact with these springs if the force of the blow has not already thrown the bulb out of contact before breaking it. The circuit is thus interrupted and the lamp extinguished.



PRINCIPAL PARTS OF GENERAL ELECTRIC LAMP WITH STEEL CASING.



A. GENERAL ELECTRIC LAMP WITH STEEL CASING, APPROVAL NO. 13.



B. GENERAL ELECTRIC LAMP WITH CAST ALUMINUM CASING, APPROVAL NO. 13A.

The effectiveness of this device was tested in the standard manner on three occasions. The first two series of tests developed the necessity for changes in the bulb and contact springs, and after these were made the tests were repeated with satisfactory results.

The maximum current that could be obtained by short-circuiting the battery provided with this lamp was determined by the standard tests to be about 73.8 amperes, which is a safe value for batteries of this type.

TENDENCY TO UNEXPECTED EXTINCTION.

Tests of the tendency to unexpected extinction, made in the standard way, showed that the bulb was thrown out of contact with the

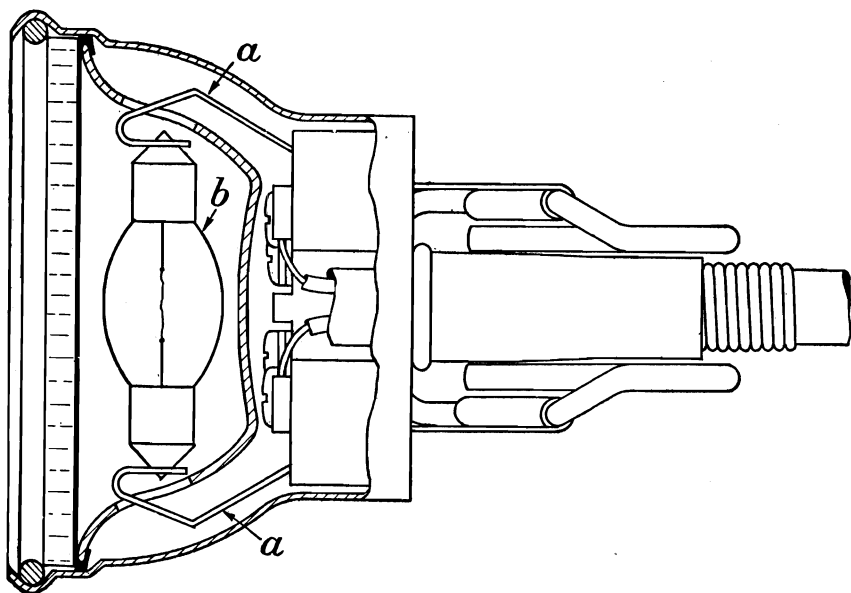


FIGURE 4.—Cross section of headpiece of General Electric lamp. Section at right angles to view shown in figure 3.

contact springs rather too easily, and the manufacturers were advised to remedy this by making the springs stiffer.

SPILLING OF ELECTROLYTE.

The batteries passed the standard tests without spilling a drop of electrolyte. Several different designs of spilling plugs were tested before a satisfactory one was developed.

LIGHT-PRODUCING CAPACITY.

AMOUNT OF LIGHT.

Three lots of 1,000 bulbs each were submitted in connection with the lamp before a satisfactory bulb (symbol BM-13) was obtained. The amount of light produced is shown in the table following.

Amount of light produced by the General Electric lamp, approvals Nos. 13 and 13A.

Average candlepower after burning 1 hour.....	1.0
Average candlepower after burning 12 hours.....	0.68
Total lumens after burning 1 hour.....	3.63
Total lumens after burning 12 hours.....	2.47

DISTRIBUTION OF LIGHT.

The distribution of light from the headpiece of this lamp, using a detachable porcelain enamel reflector, was considered satisfactory.

TIME OF BURNING.

It was determined by the standard tests that the lamp would burn on an average of about 14½ hours on one charge of battery before the battery voltage fell below the minimum value recommended by the manufacturers.

BULB CHARACTERISTICS.

The bulbs approved by the Bureau of Mines for use with this lamp were made by the Edison Lamp Works of the General Electric Co., at Harrison, N. J., and are identified by the symbol BM-13. These bulbs burned in the standard tests for more than 300 hours (the minimum test requirement for bulbs used with a lead battery) and would undoubtedly have averaged much more than this figure if the bulbs had been burned to extinction, or until their candlepower had fallen below the test requirements.

The table following gives the characteristics of the BM-13 bulbs:

Characteristics of the BM-13 bulbs for the General Electric lamp.

Percentage of bulbs lasting less than 250 hours ^a	5.0
Broadside candlepower ^b after burning one hour.....	0.767
Current consumption after burning one hour, ^c amperes....	0.607
Percentage of bulbs that consumed 6 per cent more current than the average.....	0.0
Percentage of bulbs that were more than 30 per cent below the average candlepower.....	0.0

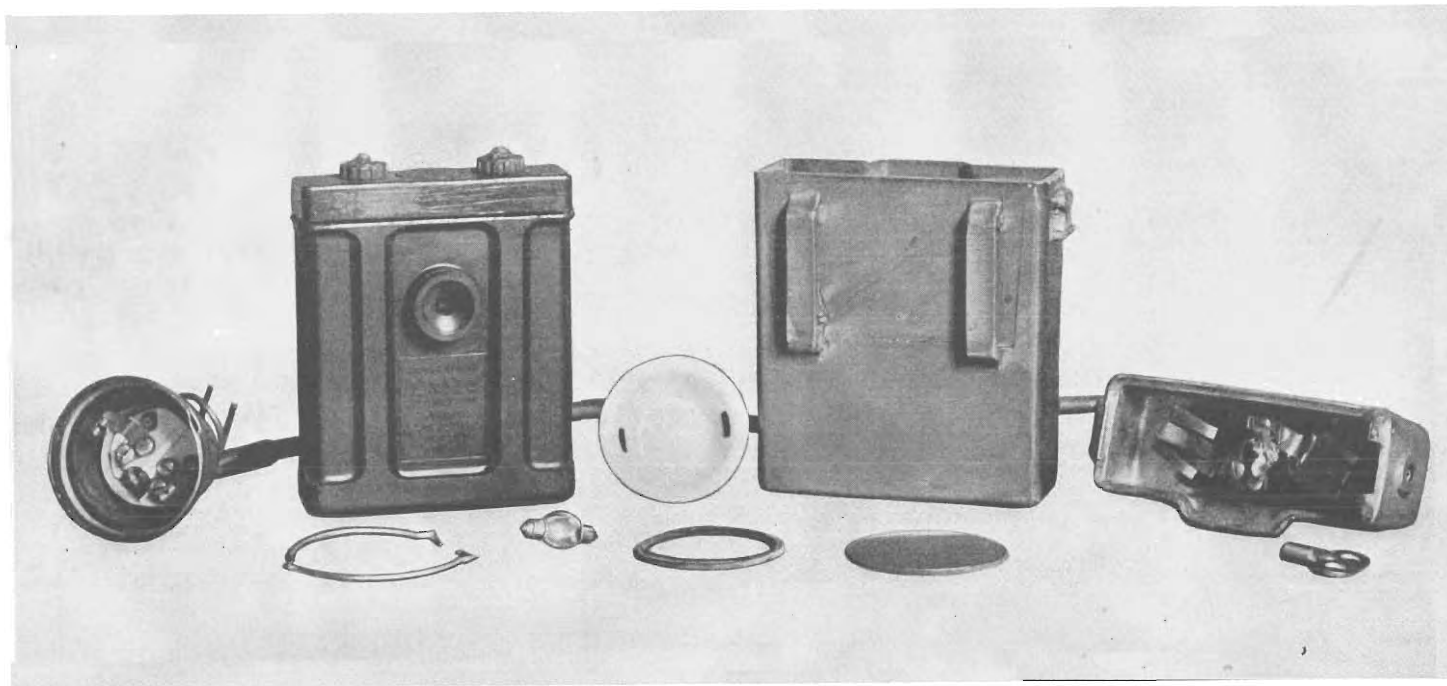
LIFE OF BATTERIES.

The batteries gave excellent service during the comparatively brief time that they were on test at the laboratory and showed no evidence of early deterioration.

^a The minimum test requirement for bulbs used with a lead-battery lamp.

^b Candlepower measured with the filament loop broadside to the photometer screen.

^c These measurements were made at the average voltage manifested by the lamp battery after it had been discharging for one hour.



PRINCIPAL PARTS OF GENERAL ELECTRIC LAMP WITH CAST ALUMINUM CASING.

LIFE OF CORDS.

Four different types of cord were tested before a cord of acceptable durability was found. This cord gave satisfactory results in the tests, but since then the bureau's researches have developed a cord that is much more durable and the bureau has recommended to the manufacturer that a cord of this type be substituted for the one originally approved with the lamp.

MECHANICAL AND ELECTRICAL CHARACTERISTICS.

The mechanical strength of both forms of the lamp was tested in the standard way and passed the tests. A number of changes in construction were made at the suggestion of the bureau engineers during the time that the lamp was under test.

These changes include the incorporation of a safety device, improvements in the characteristics of the bulbs and in the device to prevent spilling, introduction of cord clamps, and improvements in the distribution of light, in the character of cord and cord armor, and in the strength of the battery jar and the character and durability of the lock.

The lamp in both the forms that were approved is durable and reliable. They were approved with recommendations by the Bureau of Mines for (1) the substitution of a more durable cord, (2) introduction of stiffer contact springs for both battery and bulb, (3) improvement in the design and construction of the cord clamp, and (4) improvement in the character of the rubber gasket used to make the headpiece dust-tight. The aluminum-casing lamp was approved with a recommendation that the yoke over the hinge slot in the battery casing be strengthened. The manufacturer has taken these suggestions under consideration.

WICO LAMP, APPROVAL NO. 14.

The Wico lamp, submitted by the Witherbee Igniter Co., of Springfield, Mass., is a cap lamp operated by a single cell of lead battery. The lamp weighs about 4½ pounds and has a capacity of about 35.2 lumen-hours for a 12-hour shift. It is provided with a snap lock opened with a key. A detailed description of the lamp is given in Table 1 (p. 44). The assembled equipment is shown in Plate X, B, and its component parts are shown in Plate XV.

The lamp was tested in accordance with the requirements of Schedule 6A and after numerous changes in construction had been made was approved by the Bureau of Mines on June 10, 1916, for safety and for practicability and efficiency in general service (approval No. 14).

GAS-IGNITION TESTS.

The device that is designed to prevent gas ignition is shown in figure 5. The lamp bulb *b* is held in its socket *c* by a wire stirrup *a* against the pressure of spring contacts *d* within the socket that act to eject the bulb if the stirrup be removed or the bulb broken. It was necessary to modify several times the device originally submitted before it was satisfactory.

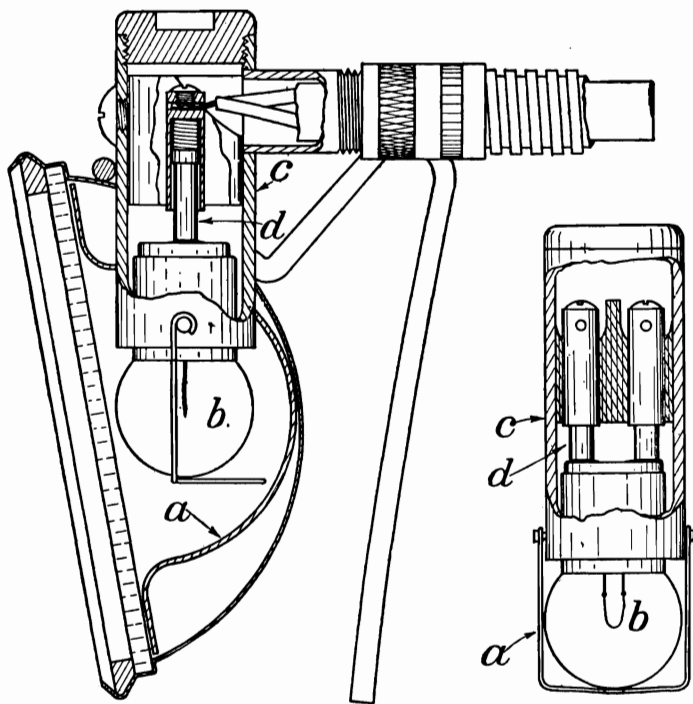


FIGURE 5.—Sectional view of headpiece of Wico lamp, showing principle of safety devices.

The maximum current that could be obtained by short-circuiting the lamp was determined by the standard test to be about 81 amperes, which is a safe value for batteries of this type.

TENDENCY TO UNEXPECTED EXTINCTION.

The tendency to unexpected extinction was tested in the standard way and the lamp was found to be satisfactory in this respect.

SPILLING OF ELECTROLYTE.

The batteries passed the standard test without spilling a drop of electrolyte.

LIGHT-PRODUCING CAPACITY.

AMOUNT OF LIGHT.

Only one type of bulb (symbol BM-14) was approved in connection with the Wico lamp. The amount of light produced is shown in the table following:

Amount of light produced by the Wico lamp, approval No. 14.

Average candlepower after burning 1 hour.....	0.93
Average candlepower after burning 12 hours.....	0.69
Total lumens after burning 1 hour.....	3.37
Total lumens after burning 12 hours.....	2.50

DISTRIBUTION OF LIGHT.

The distribution of light from the headpiece first submitted with the lamp was not sufficiently uniform to meet the test requirements. The manufacturers, therefore, experimented until a satisfactory reflector was obtained. This reflector is made from sheet aluminum treated with a solution of caustic soda and is detachable. The distribution of light from it was measured in the standard way and was found to meet the test requirements satisfactorily.

TIME OF BURNING.

It was determined by the standard tests that the lamp would burn on an average about 17 hours on one charge of battery before the battery voltage fell below the minimum value recommended by the manufacturers.

BULB CHARACTERISTICS.

Five lots of different bulbs (of 1,000 bulbs each) were submitted for test in connection with the lamp. One lot, made by the Edison Lamp Works of the General Electric Co., at Harrison, N. J., was approved and the symbol BM-14 was assigned to these bulbs. This lot of bulbs burned in the standard tests for more than 300 hours (the minimum test requirement for bulbs used with lead battery) and undoubtedly would have averaged more than that figure if the bulbs had been burned to extinction or until their candlepower had fallen below the test requirements. The table following gives the characteristics of the BM-14 bulbs.

Characteristics of BM-14 bulbs made for the Wico lamp.

Percentage of bulbs lasting less than 250 hours, ^a	5.0
Broadside candlepower ^b after burning 1 hour ^c	0.580
Current consumption after burning 1 hour, ^c amperes.....	0.523
Percentage of bulbs that consumed 6 per cent more current than the average.....	0.0
Percentage of bulbs that were more than 30 per cent below the average candle power.....	0.0

LIFE OF BATTERIES.

The Wico lamp batteries gave the best of service during the comparatively brief time that they were on test and gave no evidence whatever of early deterioration.

LIFE OF CORDS.

The cord submitted with the lamp gave good results, but before the tests of the lamp were completed cords had been developed that gave much better results, and the bureau engineers recommended to the manufacturer that one of several cords be substituted for the one originally submitted with the lamp.

MECHANICAL AND ELECTRICAL CHARACTERISTICS.

The mechanical strength of the lamp, as determined by the standard tests, proved satisfactory. During the tests a number of changes in construction were made by the manufacturers at the bureau's suggestion, as follows:

A safety device was added to the headpiece.

The construction of the headpiece was simplified and made dust tight with an improved ring for retaining the outer glass.

The character of the cord armor and the location of the cord clamp was improved.

The design and construction of the battery contact springs and the general arrangement of parts in the cover of the battery casing were improved.

A self-contained snap lock was substituted for the detachable padlock for locking the battery casing.

The efficiency of the reflector and the distribution of light from it were improved.

The lamp in the form approved is durable and reliable, and was approved with a recommendation by the Bureau of Mines that the

^a The minimum test requirement for bulbs used with a lead-battery lamp.

^b Candlepower measured with the filament loop broadside to the photometer screen.

^c These measurements were made at the average voltage manifested by the lamp battery after it had been discharging for one hour.

light-producing capacity of the bulbs be increased if this modification could be made without shortening the life of the bulbs below the bureau's requirements. The bureau also recommended that a more durable cord be adopted.

CONCORDIA CAP LAMP, APPROVAL NO. 15.

The cap lamp submitted by the Concordia Safety Lamp Co., of Pittsburgh, Pa., is operated by a single cell of lead battery. The lamp weighs 4.15 pounds, and has a capacity of 38.4 lumen-hours for a 12-hour shift. It is provided with a snap lock operated by an electromagnet. Detailed specifications of the lamp are given in Table 1. The assembled equipment is shown in Plate XVI, A, and its component parts are shown in Plate XVII, A.

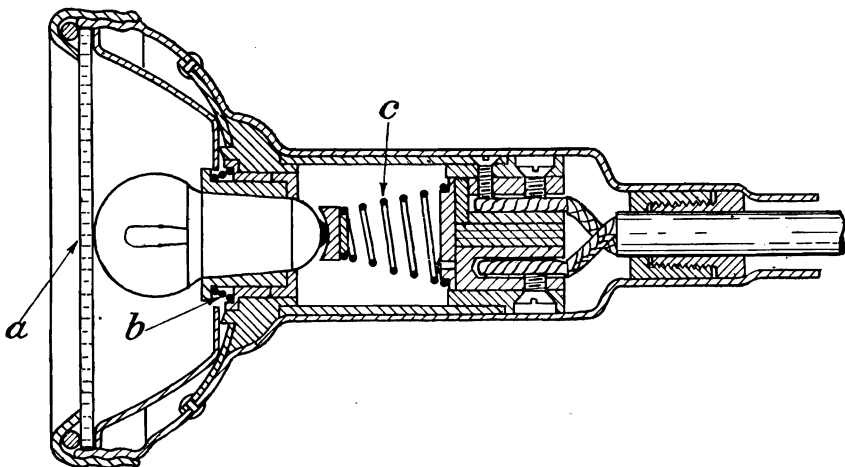


FIGURE 6.—Sectional view of headpiece of Concordia cap lamp, showing principle of safety devices.

The Concordia cap lamp was tested in accordance with the requirements of Schedule 6A and after several changes in construction had been made was approved on June 17, 1916, for safety and for practicability and efficiency in general service (approval No. 15).

GAS-IGNITION TESTS.

The device that is designed to prevent gas ignition is shown in figure 6. The outer glass *a* holds the bulb in position against the force of the spiral spring *b*, which forms one contact of the bulb, the other contact being formed by the spiral spring *c*. If either the bulb or the outer glass is broken the spring *b* pushes the bulb outward and away from the center contact *c*, the spring of which has less travel than the spring *b*. The circuit is thus interrupted and the lamp extinguished.

The effectiveness of this device was tested in the standard manner three times. The first two series of tests developed the fact that the action of the safety devices was not sufficiently protected from outside interference. The manufacturers finally reconstructed the headpiece so that it passed the tests satisfactorily.

The maximum current that could be obtained by short-circuiting the Concordia cap-lamp battery was determined by the standard test to be about 110 amperes, which is a safe value for batteries of this type.

TENDENCY TO UNEXPECTED EXTINCTION.

The tendency to unexpected extinction was tested in the standard way; the lamp proved satisfactory in this respect.

SPILLING OF ELECTROLYTE.

The batteries passed the standard test without spilling a drop of electrolyte.

LIGHT-PRODUCING CAPACITY.

AMOUNT OF LIGHT.

Only one type of bulb (symbol BM-15) was tested in connection with the Concordia cap lamp. The amount of light produced is shown in the table following:

Amount of light produced by the Concordia cap lamp, approval No. 15.

Average candlepower after burning 1 hour.....	1.05
Average candlepower after burning 12 hours.....	0.72
Total lumens after burning 1 hour.....	3.80
Total lumens after burning 12 hours.....	2.60

DISTRIBUTION OF LIGHT.

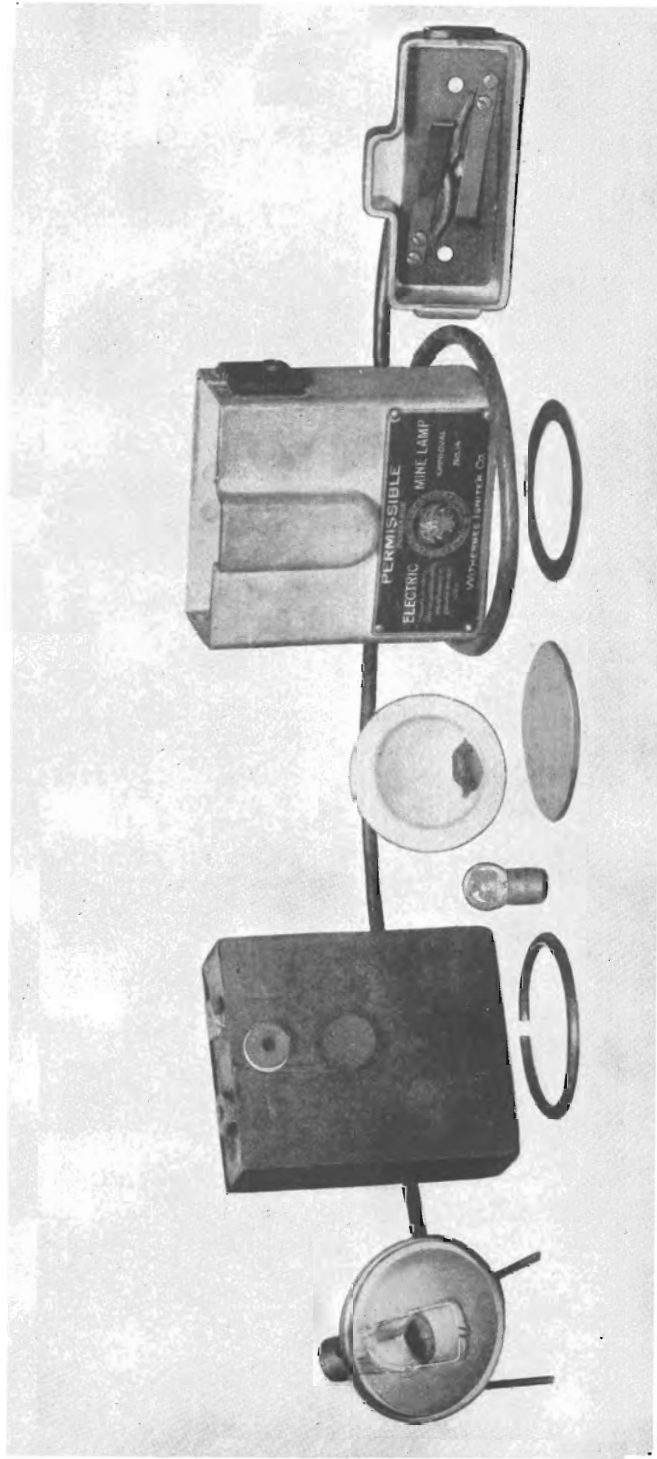
The distribution of light from the Concordia cap lamp more than met the test requirements. The reflector of the headpiece is detachable and is covered with "cleanzy" finish.

TIME OF BURNING.

It was determined by the standard tests that the lamp would burn on the average about 15½ hours on one charge of battery before the battery voltage fell below the minimum value recommended by the manufacturers.

BULB CHARACTERISTICS.

The first lot of 1,000 bulbs submitted in connection with the lamp met the test requirements. These bulbs were identified by the symbol



PRINCIPAL PARTS OF WICO LAMP, APPROVAL NO. 14.

BM-15 and were made by the National Lamp Works of the General Electric Co., Cleveland, Ohio. This lot of bulbs burned in the standard tests for more than 300 hours (the minimum test requirement for bulbs used with lead battery) and undoubtedly would have averaged much more than this figure if the bulbs had been burned to extinction or until their candlepower had fallen below the test requirements. The table following gives the characteristics of the BM-15 bulbs:

Characteristics of BM-15 bulbs for the Concordia cap lamp.

Percentage of bulbs lasting less than 250 hours ^a	2.0
Broadside candlepower ^b after burning one hour ^c	0.716
Current consumption after burning one hour, ^c amperes.....	0.805
Percentage of bulbs that consumed 6 per cent more current than the average.....	1.0
Percentage of bulbs that were more than 30 per cent below the average candlepower.....	2.0

LIFE OF BATTERIES.

The Concordia cap lamp batteries gave excellent service during the comparatively brief time that they were on test and gave no evidence of early deterioration.

LIFE OF CORDS.

The first cord submitted with the lamp did not give satisfactory service in test and the manufacturer adopted as standard a cord that had given good service during the bureau's research to develop a satisfactory mine-lamp cord.

MECHANICAL AND ELECTRICAL CHARACTERISTICS.

The mechanical strength of the lamp passed the standard tests. A number of changes in construction were made in the lamp at the suggestion of the bureau during the time that it was under investigation. These changes included improvements in the design of the cord clamp in the battery casing and the headpiece, and in the design of cord armor; better protection of the moving parts of the safety device; thicker headpiece shell and thicker bulb glass; more reliable locking mechanism; simpler construction of the contacts mounted in the cover of the battery casing.

The lamp in the form that was approved is durable and reliable. It was approved with recommendations by the Bureau of Mines for

^a The minimum test requirement for bulbs used with a lead-battery lamp.

^b Candlepower measured with the filament loop broadside to the photometer screen.

^c These measurements were made at the average voltage manifested by the lamp battery after it had been discharging for one hour.

(1) improvement in the character of the lamp cord, (2) the use of a cast aluminum casing instead of a sheet-metal casing, and (3) the development of bulbs that will give more light and still meet the bureau's requirements in regard to life of bulbs.

The writer has not been advised that these recommendations have been adopted.

PIONEER LAMP, APPROVAL NO. 16.

The Pioneer lamp, which was submitted by the Hirsch Electric Mine Lamp Co., of Philadelphia, Pa., is a cap lamp operated by a single cell of lead battery. The lamp weighs 4½ pounds, and has a capacity of about 41.6 lumen-hours for a 12-hour shift. It is provided with a screw-bolt lock operated by a spring wrench. Detailed specifications of the lamp are given in Table 1. The assembled equipment is shown in Plate XVI, *B*, and its component parts are shown in Plate XVII, *B*. The lamp was tested in accordance with the requirements of Schedule 6A, and after numerous changes in construction had been made was approved on July 21, 1916, for safety and for practicability and efficiency in general service (approval No. 16).

GAS-IGNITION TESTS.

The devices that are designed to prevent gas ignition are shown in figure 7. They consist of an open-circuiting device that protects the bulbs against blows from the front, and a short-circuiting device that protects the bulbs against blows from the side. The open-circuiting device is operated by breaking a slip of window glass, *a*, which is mounted directly across the inner surface of the outer glass, *b*. The breaking of this slip of glass releases a spring, *c*, that interrupts the electric circuit of the lamp. The short-circuiting of the bulb is accomplished as follows: The headpiece is made up of three concentric shells, *d*, *e*, and *f*, separated by a narrow space. The outer and inner shell are connected to the positive pole of the battery, and the intermediate shell is connected to the negative pole. These shells completely surround the bulb, and the theory of the safety device is that the bulb can not be broken without so jamming these shells together that they will short-circuit the bulb and thus extinguish the filament before it can ignite gas.

The effectiveness of these devices was tested in the standard way, and they were found to operate satisfactorily.

The maximum current that could be obtained by short-circuiting the Pioneer lamp battery was determined by the standard test to be 95.8 amperes, which is a safe value for batteries of this type.

TENDENCY TO UNEXPECTED EXTINCTION.

The tendency to unexpected extinction was tested in the standard way, and the lamp was found to be fairly satisfactory in this respect, although the bureau has recommended that the reliability of the lamp be increased by eliminating the circuit breaker from the headpiece and substituting an equally satisfactory safety device.

SPILLING OF ELECTROLYTE.

The batteries passed the standard tests without spilling a drop of electrolyte.

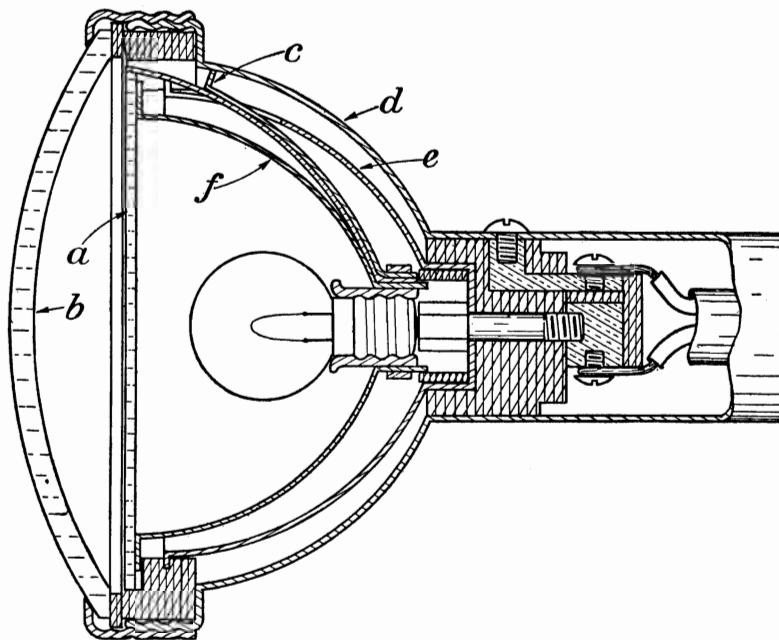


FIGURE 7.—Sectional view of headpiece of Pioneer lamp, showing principle of safety devices.

LIGHT-PRODUCING CAPACITY.

AMOUNT OF LIGHT.

Six lots of 1,000 bulbs each were submitted in connection with the Pioneer lamp before a satisfactory bulb (BM-16) was obtained. The amount of light produced is shown in the table following:

Amount of light produced by the Pioneer lamp, approval No. 16.

Average candlepower after burning 1 hour.....	1. 13
Average candlepower after burning 12 hours.....	0. 78
Total lumens after burning 1 hour.....	4. 10
Total lumens after burning 12 hours.....	2. 83

DISTRIBUTION OF LIGHT.

The distribution of light from the headpiece of the Pioneer lamp using a reflector of sheet aluminum treated with a solution of caustic soda met the test requirements.

TIME OF BURNING.

The standard tests showed that the lamp will burn on an average $15\frac{1}{4}$ hours on one charge of battery before the battery voltage falls below the minimum value recommended by the manufacturer.

BULB CHARACTERISTICS.

The bulbs approved by the Bureau of Mines for use with this lamp were made by the Edison Lamp Works of the General Electric Co., at Harrison, N. J., and are identified by the symbol BM-16. These bulbs burned in the standard tests for more than 300 hours (the minimum test requirements for bulbs used with lead battery), and would undoubtedly have averaged much more than this figure if the bulbs had been burned to extinction or until their candlepower had fallen below the test requirements.

The table following gives the characteristics of the BM-16 bulbs:

Characteristics of the BM-16 bulbs for the Pioneer lamp.

Percentage of bulbs lasting less than 250 hours ^a	2.00
Broadside candlepower ^b after burning one hour ^c	0.752
Current consumption after burning one hour, ^c amperes.....	0.60
Percentage of bulbs that consumed 6 per cent more current than the average.....	0.0
Percentage of bulbs that were more than 30 per cent below the average candlepower.....	1.0

LIFE OF BATTERIES.

The Pioneer lamp batteries gave excellent service during the comparatively brief time that they were on test and showed no signs of early deterioration.

LIFE OF CORDS.

The Pioneer lamp uses the best cord that was developed during the research to improve the character of mine-lamp cords. This cord is of exceptional durability.

MECHANICAL AND ELECTRICAL CHARACTERISTICS.

The mechanical strength of the lamp passed the standard tests. Numerous changes in construction were made in the lamp at the

^a The minimum test requirement for bulbs used with a lead-battery lamp.

^b Candlepower measured with the filament loop broadside to the photometer screen.

^c These measurements were made at the average voltage manifested by the lamp battery after it had been discharging for one hour.

suggestion of the bureau during the time that it was under investigation. Improvements were made in the character of the safety device, battery, and bulbs, in the mechanical strength of the casing and the battery jar, in the character of the cord and armor, and in the distribution of light.

The lamp that was approved is durable and sufficiently reliable. It was approved with a recommendation that the safety device be so redesigned that it will not require the use of the circuit breaker in its present form.

SUMMARY OF RESULTS OF TESTS.

The characteristics of the various approved electric miner's lamps are summarized in Table 1.

The approved lamps are considered safe, practicable, and efficient for general service in mines. All passed the safety tests satisfactorily and in general they are durable and well constructed. The batteries require intelligent care but not so much, or of such a highly specialized nature, as to be a burden to the mine operator. If the instructions issued by the lamp manufacturers are followed the batteries should render good service with a reasonable amount of attention and at a reasonable cost for labor and supplies.

All the lamps give more light than a safety lamp and distribute the light better. The lamps are reliable in operation and in general are easy to repair. The life of the batteries and the bulbs promises to be reasonably long, and the bulbs that have been approved are exceptionally uniform in their characteristics.

In short all of these lamps have all the qualifications set forth on pages 10 and 11 as essential for a safe and practical electric mine lamp.

Nearly all the lamps can be improved in some minor respects, and these improvements no doubt will be made as soon as the need becomes sufficiently manifest.

The trend of development will probably be toward producing a greater amount of light and refining the various parts of the equipment. Undoubtedly the lamps will be made simpler and still more reliable and efficient, although it is not probable that their weight will be materially reduced until there is some radical improvement in the design of storage-battery cells or of incandescent bulbs.

The rapidity with which mine operators have adopted the approved portable electric lamps has been most gratifying. The first lamp was approved in February, 1915, and in August, 1916, about 70,000 approved lamps were in use in the mines of this country, and more lamps were being installed at the rate of about 2,000 a week.

Safety in mines should be decidedly increased by this widespread substitution of the electric lamp for the flame lamp.

TABLE 1.—Detailed information regarding the portable electric miner's lamps approved by the Bureau of Mines.

Name of manufacturer.....	Edison Storage Battery Co.	Concordia Safety Lamp Co.	General Electric Co.	General Electric Co.	Witherbee Ig- niter Co.	Concordia Safety Lamp Co.	Hirsch Electric Mine Lamp Co.
Bureau of Mine's approval No.	10.	12.	13.	13 A.	14.	15.	16.
Type of lamp.....	Cap.	Hand.	Cap.	Cap.	Cap.	Cap.	Cap.
Average candlepower of light stream ^a	0.96 ^b	0.70.	0.84.	0.84.	0.81.	0.88.	0.96.
Capacity, average lumen-hours per 12-hour shift ^c	41.8 ^b	73.	36.6.	36.6.	35.2.	38.4.	41.6.
Weight of lamp, pounds.....	3.94.	5.54.	4.41.	4.74.	4.23.	4.15.	4.21.
Number of cells.....	2.	1.	1.	1.	1.	1.	1.
Kind of plates.....	Nickel-iron.	Lead.	Lead.	Lead.	Lead.	Lead.	Lead.
Kind of electrolyte.....	Alkaline.	Acid.	Acid.	Acid.	Acid.	Acid.	Acid.
Character of battery jar.....	Steel.	Celluloid.	Hard rubber.	Hard rubber.	Hard rubber.	Celluloid.	Hard rubber.
Character of case.....	Sheet steel.	Heavy steel.	Sheet steel.	Cast aluminum.	Cast aluminum.	Sheet steel.	Cast aluminum.
Type of lock.....	Snap lock oper- ated by key.	Magnetic snap lock.	Snap lock oper- ated by key.	Snap lock oper- ated by key.	Snap lock oper- ated by key.	Magnetic snap lock.	Screw-pin lock.
Character of cord armor.....	Flexible metallic tube, not rein- forced.	None used.....	Double spiral wire.	Double spiral wire.	Flexible metallic tube, rein- forced with spiral wire.	Flexible metal- lic tube, rein- forced with spiral wire.	Double spiral wire.
Kind of reflector.....	"Clean-e-z-y" finish.do.....	Porcelain.....	Porcelain.....	Treated alumi- num.	"Clean-e-z-y" finish.	Treated alumi- num.
Bulb symbol No.	BM-10.	Osram 08510.	BM-13.....	BM-13.....	BM-14.....	BM-15.....	BM-16.....
Name of bulb manufacturer.....	National Lamp Works of Gen- eral Electric Co.	A u e r g e s e l l - s c h a f t , o f B e r - l i n , G e r m a n y .	Edison Lamp Works of Gen- eral Electric Co.	Edison Lamp Works of Gen- eral Electric Co.	Edison Lamp Works of Gen- eral Electric Co.	National Lamp Works of Gen- eral Electric Co.	Edison Lamp Works of Gen- eral Electric Co.
Cord symbol No.	CD17.....	No cord used...	CD21.....	CD21.....	CD1.....	CD17.....	CD31.
Average cord service, number of operations ^d	87,000.do.....	150,000.	150,000.	26,500.	102,000.	771,700.
Special features.....							

^a Average of 100 bulbs that had been burned 150 hours, represents the average between candlepower of lamp after burning 1 hour and candlepower after burning 12 hours.

^b Performance with best bulb available.

^c This value has the same basis as "Average candlepower."

^d Refers to the average number of operations given by the cord when tested in the cord-testing machine described on page 21.

PROCEDURE FOR BUREAU OF MINES TESTS OF PORTABLE ELECTRIC MINE LAMPS.

The procedure of the Bureau of Mines in making tests to establish a list of permissible portable electric lamps for use in mines, the fees charged, the character of the tests, and the conditions under which lamps will be tested by the bureau, as set forth in Schedule 6A, issued under date of February 3, 1915, are given below:

DEFINITION OF PERMISSIBLE.

The Bureau of Mines considers a portable electric lamp to be permissible for use in mines if all the details of the lamp's construction are the same in all respects as those of the lamp that passed the inspection and the tests for safety, practicability, and efficiency made by the bureau and hereinafter described.

CONDITIONS UNDER WHICH LAMPS WILL BE TESTED.

The conditions under which the Bureau of Mines will examine and test portable electric lamps to establish their permissibility are as follows:

1. The tests will be made at the experiment station of the Bureau of Mines at Pittsburgh, Pa.

2. Applications for tests shall be addressed to the Director, Bureau of Mines, Washington, D. C., and shall be accompanied by a complete description of the lamp to be tested and a full set of the drawings mentioned below.

A drawing or drawings clearly showing the size and general appearance of the lamp mounting.

A drawing or drawings clearly showing the character, size, and relative arrangement of the parts of the lamp mounting, and the principle of operation of the safety devices.

Any other drawings that may be necessary to identify the safety devices or to explain how they accomplish their purpose.

A copy of the description, a duplicate set of drawings, and one complete lamp shall be sent to the electrical engineer, Bureau of Mines, Fortieth and Butler Streets, Pittsburgh, Pa.

3. As soon as possible after the receipt of his application for test the lamp manufacturer will be notified of the date on which his lamps will be tested and the amount of material that it will be necessary for him to submit.

4. All material for test shall be delivered by the manufacturer to the electrical engineer, Bureau of Mines, Fortieth and Butler Streets, Pittsburgh, Pa., not less than one week prior to the date set for the test.

5. No lamp equipment will be tested unless it is in the completed form in which it is to be put on the market.

6. Lamps so constructed that they can be used both as cap lamps and as hand lamps must pass the tests for both cap lamps and hand lamps or they will not be approved for either class of service.

7. No one is to be present at these tests except the necessary Government officers, their assistants, and one representative of the manufacturer of the lamp to be tested, who shall be present in the capacity of an observer only.

The conduct of the tests shall be entirely in the hands of the bureau's engineer in charge of the investigation. While the tests are in progress the manufacturer's representative shall not make unsolicited suggestions or criticisms of the method of conducting the test.

8. The tests will be made in the order of the receipt of application for test, provided that the necessary lamp equipment is submitted at the proper time.

9. The details of the results of the tests shall be regarded as confidential by all present at the tests and shall not be made public in any way prior to their official publication by the Bureau of Mines.

REQUIREMENTS FOR APPROVAL.

The requirements that a portable electric-lamp equipment must have, to pass successfully the inspection and tests required by the bureau, are stated below:

1. The lamp equipment must comply with the following requirements for mechanical and electrical construction:

The construction of permissible portable electric-lamp equipment shall be especially durable. All parts shall be constructed of suitable material of the best quality and shall be assembled in a thorough workmanlike manner. Current-carrying parts shall be well insulated from parts of opposite polarity and from parts not intended to carry current.

The battery shall be inclosed in a locked or sealed box so constructed as to preclude the possibility of anyone meddling with the electrical contacts or making an electrical connection with them while the box cover is closed.

The leads connecting the battery with the headpiece shall be made up in a single cable efficiently insulated and provided, where it leaves the battery casing and enters the headpiece, with a reinforcement of flexible metallic tubing. The flexible metallic tubing will not be required if other equally durable means of reinforcement are provided.

It is recommended, but not required, that the headpiece be so designed that it can be sealed or locked. The battery terminals and leads connecting thereto and the gas vent of the battery shall be so designed and constructed as to prevent corrosion of the battery terminals or of the essential metallic parts mounted in the cover of the battery casing.

The following qualities will be considered in determining the excellence of the mechanical and electrical construction of lamps covered by these specifications:

Simplicity of design; mechanical strength of parts and fastenings; suitability of material used; design of moving and removable parts; design and construction of terminals and contacts for permanence and electrical efficiency; and ease of repair.

2. The lamp equipment must be provided with a safety device or devices as follows:

Permissible portable electric lamps shall be so designed and constructed that whenever the bulb of a completely assembled lamp equipment is broken the lamp filament shall at once and under all circumstances cease to glow at a temperature that will ignite explosive mixtures of mine gas and air.

The mounting of the bulb may be designed so that a blow sufficient to break the bulb will short-circuit it, open the electric circuit of the lamp, or otherwise insure that the filament will be wholly or practically extinguished. All safety devices with which the lamps are provided shall be so completely protected

from injury or disturbance as to insure that the devices will always be in condition to perform their functions.

The design of the safety features shall be such that their action can not readily be hindered or prevented. The design of the safety devices shall be such that they will not act to extinguish the lamp unnecessarily.

3. The lamp equipment must be provided with a battery having a short-circuit current not in excess of the values here specified.

The bureau's engineers have made tests (reported in Technical Paper 47 of the bureau) which have satisfied them that mine gas can not be ignited by the sparks from portable electric-lamp equipments if the batteries used with such equipments are made so that their maximum short-circuit current can not exceed the following values: For batteries giving 2.5 volts or less, 125 amperes; for batteries giving more than 2.5 volts but not more than 4 volts, 85 amperes; for batteries giving more than 4 volts but not more than 6 volts, 65 amperes; for batteries giving more than 5 volts but not more than 6 volts, 45 amperes. Therefore, lamps whose short-circuit current does not exceed these values will be considered satisfactory in that respect.

4. The lamp equipment must meet the following requirements for time of burning, flux of light, intensity of light, and distribution of light:

All portable electric lamps offered for test under the provisions of this schedule shall produce for 12 consecutive hours on one charge of battery a light stream having an average intensity of light not less than four-tenths of a candlepower. The total flux of light produced by cap lamps shall not fall below $1\frac{1}{2}$ lumens during the 12 hours, and the total flux of light produced by hand lamps shall not fall below 3 lumens during the 12 hours.

The distribution of light by lamps that use reflectors shall be determined both by observation and by photometric measurement. The lamps shall be placed so that the filaments are 20 inches away from a plane surface that is perpendicular to the axis of the light stream of the lamp. When so placed the lamp shall illuminate a circular area not less than 7 feet in diameter.^a All observations and measurements of distribution shall be referred to this 7-foot circle regardless of how large an area the lamp may illuminate. As observed with the eye there shall be no "black spots" within the 7-foot circle nor any sharply contrasting areas of bright and faint illumination anywhere. As measured with a photometer the distribution of light diametrically across the circle shall fulfill the following requirements:

The curve of light distribution along the diameter of the circle shall be obtained by rotating the lamp, and thus obtaining the average distribution curve.

The average illumination in foot-candles on the best-illuminated one-tenth of the diameter shall be not more than three times the average illumination throughout the diameter, and for at least 40 per cent of the diameter the illumination shall be not less than the average.

5. The lamp equipment must be provided with lamp bulbs that meet the following requirements for variation in current consumption, variation in candlepower, and length of life:

The bulbs submitted for test shall be identified by the name of the manufacturer and by a number or symbol with reference to which approval will be granted.

The current consumption of at least 95 per cent of the bulbs tested shall not exceed by more than 6 per cent the average current consumption of all the bulbs examined.

^a This requirement will be met by lamps that have an angle of light stream of 130° or more.

The candlepower of at least 90 per cent of the bulbs tested shall not fall short of the average candlepower by more than 30 per cent.

The life of a lamp bulb will be considered as the number of hours that the bulb can be burned under normal conditions of voltage before it becomes so depreciated that when used with an average, standard, freshly charged equipment it fails to produce for 12 consecutive hours the flux and intensity of light specified in paragraph 4, page 6.

The average life of lamp bulbs shall be not less than 300 hours for acid storage batteries and not less than 200 hours for primary batteries and for alkaline storage batteries. Not more than 5 per cent of the bulbs examined shall give less than 250 hours' life with acid batteries nor less than 150 hours' life with primary batteries and alkaline batteries.

6. The lamp equipment must comply with the following requirements as to leakage of electrolyte:

Lamps shall be so designed and constructed that they will not spill nor leak electrolyte throughout an 8-hour test, during which they will be placed in any position or sequence of positions that in the opinion of the bureau's engineers will be most likely to prove whether or not the electrolyte can be spilled.

CHARACTER OF TESTS TO WHICH LAMPS WILL BE SUBJECTED.

DESIGN AND CONSTRUCTION.

The excellence of the mechanical and electrical features of the design and construction of the lamps will be carefully determined.

The following tests will also be made: Hand lamps and the headpieces of cap lamps will be dropped 10 times upon a concrete floor from a point 6 feet above it. As the result of these dropping tests there must be no breakage of the battery jar nor material distortion of the casing of the battery or of the shell of the headpiece. The engineers in charge of the investigation shall be the sole judges of whether or not material distortion occurs. The dropping tests of the headpiece must demonstrate that the safety devices will not operate unnecessarily.

Cap lamps will be dropped 10 times upon a wooden floor from a point 3 feet above it. There must be no breakage of the battery jar nor material distortion of the casing.

SAFETY DEVICES.

In making tests of the safety devices it will be assumed that if the short-circuit current of the battery does not exceed a certain value, stated previously, the glowing filament of the lamp is the only source of danger.

It will also be assumed (based on tests reported in Technical Paper 23) that the glowing filament presents an element of danger in the presence of mine gas if the bulb of the lamp can be broken without causing the filament to become wholly or practically extinguished as the result of the action of the safety devices with which the lamp is provided.

The tests will therefore be made with a view to determining whether or not the lamp bulb may be broken without causing the safety device of the lamp to extinguish the lamp or cause the filament to glow at a temperature that is not high enough to ignite explosive mixtures of mine gas and air.

If the safety devices are designed to extinguish the lamp before the bulb is broken, it will not be necessary to make the tests in gas unless the safety devices do not completely extinguish the lamp. It will then be necessary to

determine whether or not the filament is glowing at a temperature sufficient to ignite gas.

If the safety devices are designed to extinguish the lamp at the same time that the bulb is broken, it will be desirable to make the tests in explosive mixtures of gas and air.

Gas, if used, will be the natural gas supplied to the city of Pittsburgh. The composition of this gas, as determined from recent analyses, is approximately 53.1 per cent methane, 16 per cent ethane, 0.9 per cent nitrogen, and a trace of carbon dioxide.

The details of conducting the tests will manifestly not be the same for all lamps submitted, because different lamps will no doubt have safety devices differing in design, construction, and basic principles. The bureau proposes to determine for each lamp separately a schedule of tests that, after due examination of the lamp and its safety devices, seem best adapted to ascertaining the merits of the equipment submitted. This schedule may be examined and discussed by the manufacturer's representative before the tests are begun.

In general, the tests will consist of striking the mounting or holder of the lamp bulb in an attempt to break the bulb without extinguishing the lamp.

If the safety devices are designed to extinguish the lamp (as by disconnecting the bulb from circuit or by opening the circuit at some other point), the devices will be considered to have acted—

1. If, after the blow has been delivered, the lamp bulb, whether broken or not, is clearly disconnected from circuit.

2. If, after the blow has been delivered—

- (a) When the lamp filament is not broken by the blow, it does not glow, or

- (b) When the lamp filament is broken by the blow, a sound filament, replacing the broken filament, does not glow.

If the safety devices are designed to decrease the temperature of the filament (by short-circuiting the filament or by other means), the devices will be considered to have acted if, after the blow has been delivered—

- (a) When the lamp filament is not broken by the blow, it does not glow at a temperature sufficient to ignite gas, or

- (b) When the lamp filament is broken by the blow, a sound filament, replacing the broken filament, does not glow at a temperature sufficient to ignite gas.

If there is any question as to whether or not a filament is glowing at a dangerous temperature, the point will be settled by surrounding the filament with an explosive mixture of gas and air.

If, after the blow has been delivered, the bulb has not been broken and the safety devices have not acted, the test will be repeated with the same equipment or with a different equipment, at the discretion of the bureau's engineers.

The bureau believes that approximately 50 tests will be necessary to determine whether or not the safety devices of a lamp are permissible for use in gaseous mines, but more or fewer tests may be made at the discretion of the engineer in charge of the tests.

DETERMINATION OF MAXIMUM SHORT-CIRCUIT CURRENT.

The short-circuit current of the battery will be measured under conditions that will give the same current that would flow through a short circuit between the conductors of the flexible cord at the point in the cord nearest to the battery casing.

TIME OF BURNING, FLUX OF LIGHT, INTENSITY OF LIGHT, AND DISTRIBUTION OF LIGHT.

The tests to determine the time of burning, flux, intensity, and distribution of light will be made for not less than 20 batteries, 6 reflectors or lamp mountings, and 100 lamp bulbs.

The average performance of the various equipments will be taken as the average performance of the lamp. The measurements of flux and intensity of light will be made after the bulbs have been burned for about 10 hours in order to season them somewhat.

VARIATION IN CURRENT CONSUMPTION, CANDLEPOWER, AND LIFE OF BULBS.

Measurements of current consumption and candlepower will be made with bulbs that have been burned about 10 hours.

Measurements of current consumption will be made at approximately the average potential given by the lamp battery after having been used for one hour.

Measurements of bulb candlepower will be made in one direction only. Usually the direction that gives the largest exposure of filament will be selected.

Determination of bulb life will be made with batteries that have the same voltage characteristics as those used with the lamp. Tests will be made with the bulbs in a fixed position.

Although, as stated in Technical Paper 75, Bureau of Mines, the bureau considers that the batteries of portable electric mine lamps should give 3,000 hours of service (300 12-hour shifts) without requiring repairs to or replacements of any part, it is manifestly impracticable for the bureau to carry out the 3,600-hour test upon each battery submitted for approval. Therefore the requirements of the bureau with respect to the durability of batteries will be considered as satisfied if the batteries shall perform their functions without repair while being used by the bureau, in accordance with the written instructions of the lamp manufacturer to conduct the bulb-life tests, and at the completion of these tests the condition of the batteries shall give no evidences of weaknesses that indicate the early failure of any part of the battery.

LEAKAGE OF ELECTROLYTE.

The lamps will be tested for leakage and spilling of electrolyte by placing the batteries for various lengths of time, totaling eight hours, in various positions that seem most likely to cause the cells to leak or spill. If a battery does not leak or spill more than one full drop of electrolyte during the eight-hour test, the battery casing will be regarded as nonspilling.

APPROVAL OF PERMISSIBLE PORTABLE ELECTRIC MINE LAMPS.

APPROVAL PLATES.

The manufacturers will be required to attach to the battery casing of each permissible lamp equipment a plate bearing the seal of the Bureau of Mines, and inscribed as follows:

Permissible portable electric mine lamp. Approval No. —.

Issued for safety and for practicability and efficiency in general
service to the ————— Co.

The use of the plate will not be required if the same inscription is stamped or cast into the casing of the battery.

NOTIFICATION OF MANUFACTURER.

As soon as the bureau's engineers are satisfied that a lamp is permissible the manufacturer of the lamp and the mine-inspection departments of the several States shall be notified to that effect. As soon as a manufacturer receives formal notification that his lamp has passed the tests prescribed by the bureau he shall be free to advertise such lamp as permissible.

SCOPE OF APPROVAL.

The bureau's approval of any lamp shall be construed as applying to all lamps made by the same manufacturer that have the same construction in the details considered by the bureau, but to no other lamps.

Manufacturers shall, before claiming the bureau's approval for any modification of any approved lamp, submit to the bureau drawings that shall show the extent and nature of such modifications, in order that the bureau may decide whether or not it should test the remodeled lamp before approving it. Each approval of a permissible lamp will be given a serial number. Approvals of modified forms of a previously approved lamp will bear the same number as the original approval, with the addition of the letters a, b, c, etc.

WITHDRAWAL OF APPROVAL.

The bureau reserves the right to rescind, for cause, at any time any approval granted under the conditions herein set forth.

APPROVAL OF LAMP BULBS ALONE.

The bureau will, upon request, make tests of lamp bulbs to determine whether or not they will comply with the bureau's requirements when used in connection with any lamp that has been approved by the bureau under the provisions of this schedule.

Lamp bulbs that fulfill the requirements will be specifically approved for use with stated lamps.

Applications for tests of bulbs should be made in a manner similar to application for tests of lamps.

FEES FOR TESTING PORTABLE ELECTRIC MINE LAMPS.

The necessary expenses involved in testing portable electric mine lamps have been determined, and the following schedule of fees to be charged on and after the date of issue of this schedule has been established and approved by the Secretary of the Interior:

ITEM 1, COMPLETE TEST.

For a complete official investigation leading to the formal approval of a portable electric mine lamp, the investigation to include tests of the safety devices and the determination of the time of burning, flux of light, intensity of light, distribution of light, bulb characteristics, leakage of electrolyte, and durability----- \$150.00

ITEM 2, SAFETY TESTS ONLY.

For tests of the safety devices only----- 30.00
For additional necessary tests under the same investigation (for each five tests or fraction thereof)----- 2.50

ITEM 3, TESTS OTHER THAN FOR SAFETY.

For tests to determine only the time of burning, flux of light, intensity of light, distribution of light, bulb characteristics, and leakage of electrolyte----- \$120.00

ITEM 4, BULB TESTS.

For tests to determine only bulb life, variation in bulb candlepower, and variation in bulb current consumption:

If such tests involve making discharge voltage determinations---- 75.00
 If such tests do not involve making discharge voltage determinations----- 50.00

ITEM 5, INDIVIDUAL TESTS.

The following charges will be made for individual tests included under item 3:

Discharge voltage tests-----	25.00
Reflector tests-----	20.00
Time of burning tests-----	10.00
Light distribution tests-----	5.00
Electrolyte spilling tests-----	3.00
Short-circuit tests of battery-----	1.00
Mechanical tests of cord-----	6.00
Bulb life tests-----	35.00
Bulb uniformity tests-----	15.00

ITEM 6, SPECIAL TESTS.

Special tests that circumstances shall render necessary during the course of the investigation will be made at the request of the lamp manufacturer and will be charged for in accordance with the amount of work involved.

REMITTANCES.

Manufacturers who submit lamps for tests to determine permissibility for use in gaseous mines will be required to furnish certified check or bank draft made payable to the Secretary of the Interior, to cover the total fees required for the desired tests. Such fees must be received at least two weeks prior to the date set for beginning the tests; otherwise the equipment of the next applicant upon the list will be tested.

SYNOPSIS OF PROCEDURE TO BE FOLLOWED IN MAKING APPLICATION FOR TESTS, SUBMITTING MATERIAL, CONDUCTING TESTS, AND NOTIFYING APPLICANT OF RESULTS.

1. Application for tests should be addressed to the Director of the Bureau of Mines, Washington, D. C. This application should be accompanied by check or draft and by a complete description of the lamp to be tested and a set of the drawings described in paragraph 2, page 45. Duplicate copies of the application, description, and drawings should be sent to the electrical engineer, Bureau of Mines, Fortieth and Butler Streets, Pittsburgh, Pa., accompanied by a single complete lamp equipment.

2. As soon as the application has been reviewed by the bureau's engineers the applicant will be notified of the date of test and the number of lamps and lamp parts that it will be necessary for him to submit.

3. After receiving this notification the applicant should send the material required to the electrical engineer, Bureau of Mines, Fortieth and Butler

Streets, Pittsburgh, Pa. This material should be delivered not less than one week in advance of the date set for the beginning of the tests. At this time the applicant should state the name and address of the applicant's representative who will witness the tests.

4. The tests will be begun on the date set and continued until the lamp is approved, rejected, or withdrawn.

5. After the bureau's engineers have considered the results of the tests, a formal report of the approval or disapproval of the lamp will be made to the applicant in writing by the Director of the Bureau of Mines. No verbal report will be made and the details of the tests must be regarded as confidential by all present.

PUBLICATIONS ON ELECTRICAL EQUIPMENT FOR MINES.

A limited supply of the following publications of the Bureau of Mines has been printed and is available for free distribution until the edition is exhausted. Requests for all publications can not be granted, and to insure equitable distribution applicants are requested to limit their selection to publications that may be of especial interest to them. Requests for publications should be addressed to the Director, Bureau of Mines.

The Bureau of Mines issues a list showing all its publications available for free distribution as well as those obtainable only from the Superintendent of Documents, Government Printing Office, on payment of the price of printing. Interested persons should apply to the Director, Bureau of Mines, for a copy of the latest list.

PUBLICATIONS AVAILABLE FOR FREE DISTRIBUTION.

BULLETIN 46. An investigation of explosion-proof mine motors, by H. H. Clark. 1912. 44 pp., 6 pls., 14 figs.

BULLETIN 52. Ignition of mine gases by the filaments of incandescent electric lamps, by H. H. Clark and L. C. Ilsley. 1913. 31 pp., 6 pls., 2 figs.

BULLETIN 68. Electric switches for use in gaseous mines, by H. H. Clark and R. W. Crocker. 1913. 40 pp., 6 pls.

TECHNICAL PAPER 4. The electrical section of the Bureau of Mines, its purpose and equipment, by H. H. Clark. 1911. 12 pp.

TECHNICAL PAPER 19. The factor of safety in mine electric installations, by H. H. Clark. 1912. 14 pp.

TECHNICAL PAPER 22. Electrical symbols for mine maps, by H. H. Clark. 1912. 11 pp., 8 figs.

TECHNICAL PAPER 23. Ignition of mine gas by miniature electric lamps with tungsten filaments, by H. H. Clark. 1912. 5 pp.

TECHNICAL PAPER 28. Ignition of mine gas by standard incandescent lamps, by H. H. Clark. 1912. 6 pp.

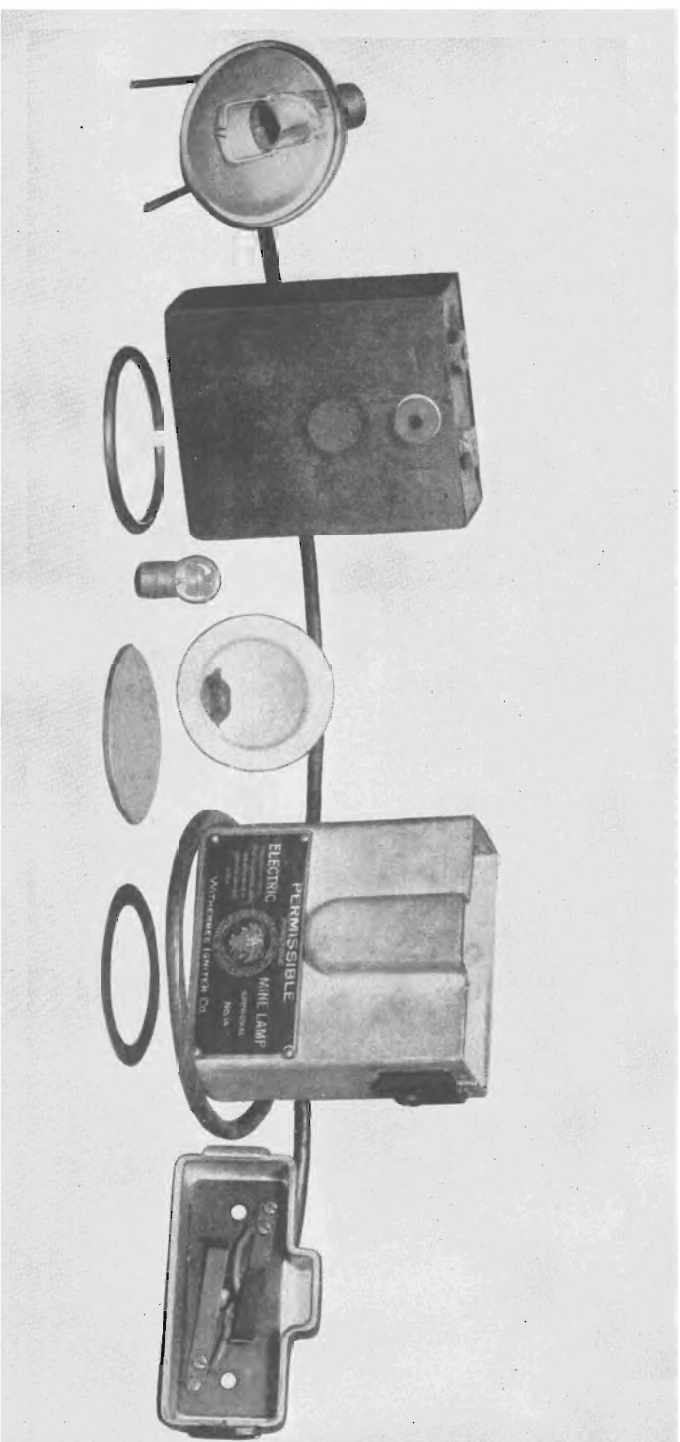
TECHNICAL PAPER 44. Safety electric switches for mines, by H. H. Clark. 1913. 8 pp.

TECHNICAL PAPER 47. Portable electric mine lamps, by H. H. Clark. 1913. 8 pp.

TECHNICAL PAPER 58. Action of acid mine water on the insulation of electrical conductors, a preliminary report, by H. H. Clark and L. C. Ilsley. 1913. 26 pp., 1 fig.

TECHNICAL PAPER 75. Permissible electric lamps for miners, by H. H. Clark. 1914. 21 pp., 3 figs.

TECHNICAL PAPER 79. Electric lights for oil and gas wells, by H. H. Clark. 1914. 8 pp.



PRINCIPAL PARTS OF WICO LAMP, APPROVAL NO. 14.

TECHNICAL PAPER 108. Shot firing in coal mines by electricity controlled from the outside, by H. H. Clark, N. V. Breth, and C. M. Means. 1915. 36 pp.

TECHNICAL PAPER 159. Production of explosives in the United States during the calendar year 1915, with notes on coal-mine accidents due to explosives and a list of permissible explosives, lamps, and motors tested prior to June 1, 1916, compiled by A. H. Fay. 1916. 24 pp.

MINERS' CIRCULAR 5. Electrical accidents in mines, their causes and prevention, by H. H. Clark, W. D. Roberts, L. C. Ilsley, and H. F. Randolph. 1911. 10 pp., 3 pls.

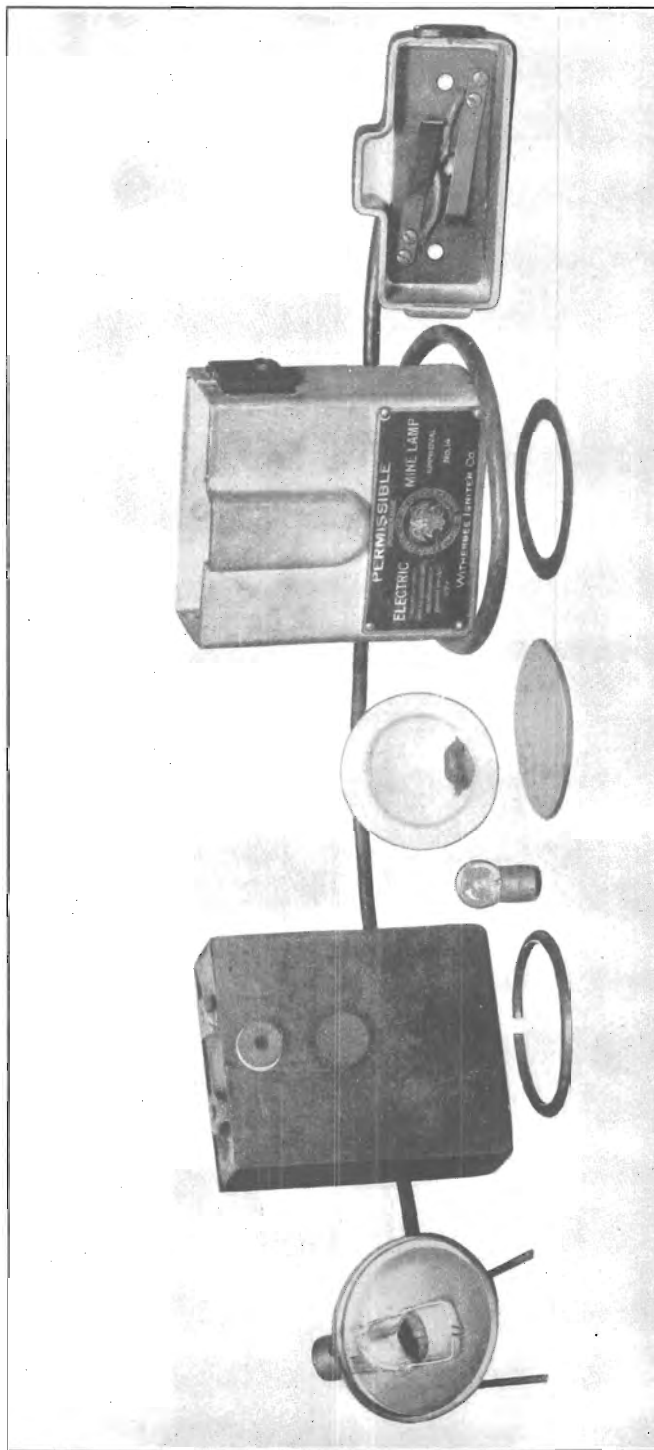
PUBLICATION THAT MAY BE OBTAINED ONLY THROUGH THE SUPERINTENDENT OF DOCUMENTS.

TECHNICAL PAPER 101. Permissible explosion-proof electric motors for mines; conditions and requirements for test and approval, by H. H. Clark. 1915. 14 pp., 2 pls., 1 fig. 5 cents.

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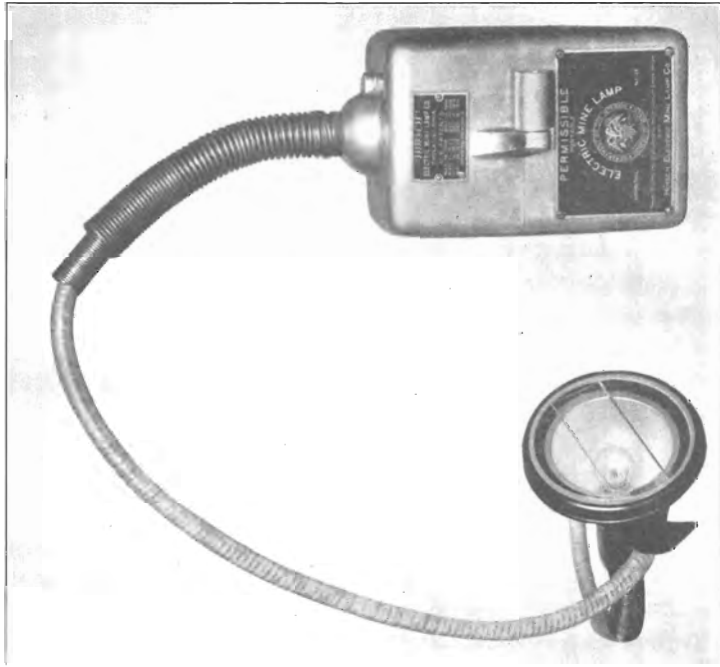
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PRINCIPAL PARTS OF WICO LAMP, APPROVAL NO. 14.



A. CONCORDIA CAP LAMP, APPROVAL NO. 15.



B. PIONEER LAMP, APPROVAL NO. 16.

