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PROTECTION AGAINST LIGHTNING AT SURFACE AND UNDERGROUND MINING PLANTS

BY

D. HARRINGTON, D. J. PARKER, AND L. H. HARRISON

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By D. Harrington,[2] D. J. Parker,[3] and L. H. Harrison[4]

INTRODUCTION

The necessity for protection against the hazards of lightning manifests itself from time to time in the mining industry by reason of loss of life, damage to electrical equipment, fires in surface structures at mines, and accidents in the handling and use of explosives. This paper is intended to assemble, correlate, and present some of the salient points embodied in the available literature on the subject and at the same time give some factual data concerning instances of such loss of life and damage to property, with special application to the mining industry.

The annual loss of life and destruction of property by lightning is considerable; the former may be prevented to a limited extent, though use of common sense as to exposure is required and not always followed; the latter can be prevented to a considerable degree. The manufacturers of electrical equipment, through improved types of lightning arresters, have done much toward the protection of electrical equipment, with consequent safeguarding of life and of property. Education based on unfortunate experiences has gone far to discourage the handling of explosives and blasting accessories during thunder storms, especially in open pits and quarries, and to a much smaller extent in underground workings. The lowly lightning rod plays an important role in the protection of certain types of buildings (especially isolated buildings), stacks, monuments, and other structures.

LIGHTNING PHENOMENA

In 1751, Franklin proved that lightning was simply a visible display of electricity - an extended spark; and until a generation ago little had been added to his exposition, to define the various phases of the phenomenon. Matters pertaining to lightning are discussed in the following references:

1/ The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Information Circular 7447."
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CIVILETT, J. A. Lightning Damage Prevented by Using Proper Apparatus. Coal Age, vol. 47, No. 11, November 1942, pp. 61-63.

OIL WORLD. Fire Prevention, Protection, Development in the California Oil Industry. September 1939, pp. 3-7.

PETERS, O. S. Protection of Life and Property Against Lightning. Bureau of Standards Tech. Paper 56, 1915, 127 pp.

RICHERT, F. W. How Lightning and Surges Can be Rendered Innocuous by Two Sets of Arresters Working in Tune. Coal Age, vol. 47, No. 5, May 1947, pp. 51, 54-55.

ROCKY MOUNTAIN COAL MINING INSTITUTE. Lightning and the Nature of Lightning. Proc. 1939, pp. 55-61.

SIMPSON, SIR GEORGE, AND SCRASE, F. J. Proc., Royal Soc., ser. A, No. 906, vol. 161, 1937.

STRONG, R. G. Possible Effect of Lightning on Underground Gas-Transmission Lines, Proc. Ann. Conv., Am. Gas Assoc., May 1939; Gas Age, vol. 83, May 25, 1939, pp. 35-36; Pipe Line News, June 1939, pp. 3-7.

UNDERWRITERS LABORATORIES. Installation Requirements for Master Labeled Lightning Protection Systems. Nat. Board of Fire Underwriters, 1934.

WAGNER, C. F., AND McCANN, G. D. Lightning Phenomena. Chap. 12, Electric Transmission and Distribution Reference Book, Westinghouse Electric & Manufacturing Co., Pittsburgh, Pa.

WILSON, C. R. T. Investigation of Losses from Lightning. Jour. Franklin Inst., vol. 20B, 1929, pp. 288-290.

EXPLOSIONS IN MINES AND QUARRIES

The very nature of lightning discharges makes it inconceivable that the electric disturbance should be confined to the atmosphere; the disturbance extends for some distance into the earth, probably in a radial pattern from the stroke center or discharge point.

Lightning discharges are initiated by invisible pilot streamers or leaders propagated from the cloud toward the earth, forming a path for the discharge. Regarding this, Wagner and McCann[6] state:

> As the leader strikes the ground an extremely bright streamer propagates upward from the earth to the cloud following the same path as the main channel of the downward leader. The charge distributed along the leaders thus is discharged progressively to ground, giving rise to the very large currents usually associated with lightning discharges - currents varying between 1,000 and 200,000 amperes.

With currents of such magnitude, even though spread over a considerable area of the earth's surface, voltage gradients are built up owing to the resistivity of the earth, which can provide sufficient potential difference to set off explosive charges primed with electric detonators and produce definite shock hazard. Such voltage differences are not confined to the earth's surface but have caused premature explosions in underground mines, and instances

6/ Wagner, C. F., and McCann, G. C., Lightning Phenomena: Chap. 12, Electric Transmission and Distribution Reference Book, Westinghouse Electric & Manufacturing Co., Pittsburgh.

are on record in which persons have received severe shocks at remote locations underground during lightning storms.

Below are some abstracts of letters and reports giving data on instances in which lightning is known or suspected to have caused premature explosions or electrical shock in mines and quarries.

> I have in mind an occurrence at the Wakefield Pit of the M. A. Hanna Co. at Wakefield, Mich., about 1922 when two well-drilled holes were loaded to be detonated with electric blasting caps; and while the men were at lunch a lightning storm came up and these holes were set off without damage to anyone. There was always a question as to whether the wires were properly "shorted" when left.
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> On May 22, 1908, at Caimito Mulato, Canal Zone, during a thunder storm, lightning exploded 31 tons of dynamite in a number of drill holes. The charges were all placed and the legs of the electric detonators were being connected to the leading wires. Two fatalities and a number of injuries resulted.
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> On August 11, 1908, at Macachin, Canal Zone, a number of holes had been charged, and the legs of the electric detonators had been connected up to the leading wires when lightning struck the circuit and exploded the whole charge. Four men were injured.
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> On November 7, 1911, at Miraflores Locks, Canal Zone, lightning set off 12 35-foot holes, in which were 1,100 pounds of 60-percent straight nitroglycerin dynamite. Electric detonators were in place in the holes but the legs had not been connected to the leading wire. The evidence is that all of the holes exploded, and it is possible that a number of these holes were fired by influence from adjacent holes. A number of men were injured but no fatalities resulted.
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> In June 1918, in an open-pit iron mine in the United States, during a thunder storm, lightning struck a bench near 34 charges, 14 of which exploded prematurely. Thirty-four charges had been placed in chambers which were reached by "gopher" holes. Two electric detonators had been placed in each charge, and the men were placing the stemming in the gopher holes, when a severe electrical storm occurred. A number of the men took shelter in an unfilled "gopher" hole. A lightning flash was seen to strike the bank near the charges, and a blast occurred immediately. Eighteen men were killed in this accident.
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> * * *
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> In August 1918, in an open-pit mine in the United States, lightning exploded prematurely two "springing" charges, which contained five sticks of 40 percent dynamite. Each charge contained an electric detonator, and the leading wires were lying on the surface. No one was injured.
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> * * *

A premature explosion of dynamite occurred late the afternoon of Thursday, June 26, 1930, in the St. Lawrence River about 3 miles above Brockville, Ontario, which demolished the drill boat, John B. King, and caused the death of at least 31 of the 42 men aboard. Evidence is that this premature explosion was caused by lightning.

The boat was equipped with 12 drills set 10 feet apart and was capable of drilling holes 10 inches in diameter and 30 feet deep. Four rows of holes had been drilled and charged. Presumably these rows were about 10 feet apart. It was estimated that the 48 holes contained somewhat less than 12 tons of dynamite. The charges were to have been fired with electric detonators and the primers were placed in most, perhaps all of the holes. The legs of the electric detonators had been connected together - presumably this means connected in series - but the drill boat had not been moved to a safe location but was directly at the edge of or perhaps over the blast location. For such subaqueous blasting special waterproof electric detonators with enameled copper legs are commonly used and it is to be presumed that this was the type that was used here.

Prior to the explosion rain accompanied by severe thunder and lightning had been observed. Lightning was observed striking the drill boat, John B. King, by Capt. G. B. Lox, in command of the United States Cutter CG. 211, and by others. Coast Guard men from this cutter rescued 10 of the 11 survivors.

This disaster calls attemtion to the hazards of lightning where electric blasting is employed and especially where the charge is placed in part or whole sometime before it is fired.

In the case of the Brockville, Ontario, explosion, it is not known whether the legs of the electric detonators or the shot-firing circuit were electrically short-circuited by twisting the wires or otherwise, but in the other cases mentioned, it is reasonably certain that this was not done in any case. This would be a wise precaution to take in any event, though the degree of protection afforded by it cannot now be definitely stated.

Notable features of this premature explosion are the fact that it was the custom of this drill boat to bring the explosive for charging in the holes to the drill boat immediately before charging and in this case it appears that but little or no explosive was on the drill boat at the time of the explosion. That 11 survivors were rescued was due to the fact that the United States Cutter CG. 211 was nearby; a flash of lightning was observed from it, as was the explosion, whereupon it proceeded promptly to the site and started the rescue operations within about 3 minutes.

* * *

The Sliver mine in St. Louis County, Minn. was first developed as an underground property in 1908 but later as an open-cut by removing 40 to 60 feet of glacial drift. The major ore body extended in an east to westernly direction. The major portion of the steam shovel operations had been conducted in the south portion of the open-cut leaving a bank of ore on the north shore line approximately 500 to 600 feet long, 40 feet high, and 100 feet wide. Old sublevel drifts from the underground operations extended from east to west in the bank, and during 1918, it was decided to drive crosscuts to the shore line in an attempt to mine the ore and stockpile it in the pit for later loading by steam shovel. This attempt was unsuccessful and it was then decided to blast the entire bank in one operation by driving coyote holes and drift, then load the ore by the steam shovels.

Timbered coyote holes were driven 50 to 60 feet into the bank at 50-foot intervals about 5 to 7 feet above the open-cut bottom. Drifts were driven in an east to westernly direction, connecting up all the coyote crosscuts. After the drifts were completed, a half carload of granular black blasting powder and 45 percent dynamite were distributed throughout the drifts. Primers consisting of electric detonators and 45 percent dynamite were placed in each charge and the wires were extended to the coyote hole openings. Stemming consisting of ore materials in bags was piled as close to the explosives as possible and the coyote holes were packed with loose ore.

The work was almost completed on Thursday, June 27, 1918, and it was decided to fire the blast on the following Sunday, when adjacent mines would be idle.

An electrical storm passed over the mine about 10 a.m. on June 27, 1918, and the heavy rain accompanying it caused the open-cut operation to be stopped; however, 13 men engaged in placing stemming in the coyote holes continued working during the storm. A shovel crew of six men sought shelter in an old timbered drift in the east end of the area which was to be blasted; this drift intersected the open-cut bottom and extended into the bank for 60 to 70 feet.

Eye witnesses are said to have testified that lightning struck the mine, and a terrific crash was heard when suddenly the ore bank seemed to open and slide away from the north shore line caving all openings.

Rescue work was started immediately, but of the 19 men in the drift and coyote holes, only 1 was saved and the other 18 lost their lives. The company had a complete map of all coyote holes but it was of little value due to the shifting and sliding of the bank.

* * *

We experienced two premature explosions in our limestone mines at Mullins, Ky., which were attributed to lightning.

In both instances we were dropping the roof, getting back upon the rock pile and drilling until we were unable, on account of the closeness of the rock pile to the roof, to do so.

In the first instance some six or eight holes had been loaded when Anderson, the foreman in charge, was notified that an electrical storm was taking place. Anderson immediately stopped loading and, together with his crew, came out of the mine. The wires from several holes had not been connected, but left hanging out loose. Shortly after Anderson and his crew got outside, a keen clap of thunder was heard, and lightning appeared to strike near the top of the hill under which our mine is located. Immediately thereafter, an explosion was heard in the mine. After the storm subsided, investigation was made, and it was found that six holes had been discharged. Since it was damp at the point the holes were drilled, some surface water dripping through, I believe the electricity which caused the detonation of the caps was conducted by water.

In the second case the circumstances were identical with the first instance, except that at the time Anderson was advised of an electrical storm taking place outside, he had connected up his holes and attached his lead line. As Anderson and his crew came out of the mine, he (Anderson) unreeled the lead line and left the unreeled portion of the lead line adjacent to a 4-inch pipe, in fact against it. This 4-inch pipe line was an air line coming from our compressor and exposed to the weather. Shortly after Anderson and his crew came out of the mine there was considerable thunder accompanied by sheet lightning, and the loaded holes were all discharged. The pipe line, in this case, was unquestionably the conductor, there being enough electrical energy in the air to detonate the E. B. caps. The lightning did not appear to strike in this case, but the whole atmosphere was charged.

* * *

The "Explosives Engineer" of October 1933, page 294, gives an account of a premature firing of 16 out of 36 holes in an underground limestone mine of the Washington Building Lime Co., Bakerstown, Jefferson County, W. Va. The account states that the men had charged 36 holes and were some distance from the surface, that the firing lines were all disconnected, and the cause of the premature blast is attributed to lightning.

* * *

Early in the season, bush fires threatened to do much damage in northwestern Quebec, but large crews and a heavy rain checked the blazes in time. The O'Brien mine at Cadillac was shut down for a day because of the nearness of fire and in Joannes Township, near Rouyn, 200 fire fighters succeeded in quelling the first "green bush" fire of the year.

The same storm that helped to put out the fires was responsible for the loss of three miners' lives at the bottom of Sladen Malartic's shaft, then at a depth of 700 feet. It was the third time a supercharged atmosphere had set off an electric blast prematurely in northwestern Quebec, although it has never happened in nearby Ontario mines where no other precautions are taken. Holes for the "square-up" round in the shaft-sinking operation had been completed, and all but the blasting crew of three had been taken up. Loading was completed, and the electric blasting caps had been connected. Fifty feet above, on the safety bulkhead, the circuit was broken. On the 500-foot level, the circuit was broken in two places, one of them a locked switch to which only the chief blaster had a key. The men were just ready to come up in the bucket when a flash of lightning crossed overhead, at least 50 feet from the headframe. The charge at the shaft bottom went off immediately. Two died instantly and the third man lived 20 minutes.7/

* * *

Lightning Explodes Dynamite 4,000 Feet Below Ground

Johannesburg, December 13. - Eight native mine workers were killed in a Rand mine December 12, 1937, when lightning struck a bell wire on the headgear of the Central Shaft and detonated 11 dynamite charges 4,000 feet underground. The men were in a party of 15, preparing dynamite charges under the supervision of two Europeans. Four other natives were seriously injured. One of the Europeans, Mr. J. J. P. Pretorious, was saved from serious injury and perhaps death, by the action of a relative, who pushed him aside in the first explosion. The mine is owned by East Rand Proprietary Mines Ltd.8/

* * *

In the summer of 1929 in the Machusett-Coldbrook Tunnel in Massachusetts, after a round had been charged and the men had left, and while both safety switches were open, lightning which accompanied a thunder storm on the surface, struck the shot-firing line, followed it down the 411-foot shaft and toward the face of the tunnel about 1 mile distant, jumped across both of the open switches, and fired the shot. Nobody was injured. Subsequent to this occurrence eight-foot gaps were introduced into the shot-firing line as a protection against premature explosion from lightning.

* * *

A fire completely destroyed a fan installation about 3:30 a.m. on August 8, 1944, at the Carbon No. 3 mine, Carbon Fuel Co.; Carbon, W. Va. An electrical rain storm was raging during the afore-mentioned date, and it is the opinion of the management that the fire was

7/ This item was taken from the Canadian Mining Journal, July 1938, vol. 59, No. 7, p. 407.

8/ Mining Journal (London) vol. 199, No. 5339, Dec. 18, 1937, p. 1124.

caused by lightning striking close to the fan. The fire penetrated into the mine workings for an approximate distance of 200 feet in the Nos. 1 and 2 east entries off the Paint Creek side. There were no men working underground at the time of the fire.

The following item was taken from the California Safety News, vol. 23, No. 1, 1939, page 11:

A storm caused three miners to lose their lives. The men were loading holes at the bottom of a shaft, using electric caps. The caps had been connected to the blasting circuit, but the circuit was not closed. In fact, it was open in three places, one of them a locked safety switch. Just as the men were ready to come up, a lightning flash crossed overhead, 50 feet or more from the head-frame; but the entire charge in the shaft was instantly set off.

Rule 24 of the Rules prepared by the Institute of Makers of Explosives says: "Don't connect up or load boreholes for electric firing during the approach or progress of a thunder storm, and if charges are already loaded and connected, all persons should be kept at a safe distance from them while the storm is in progress. If necessary to leave overnight, ends of the wires should be twisted together, coiled and covered with dirt."

A chief mine inspector wrote (in part):

At the Beattie mine, a number of holes were loaded and ready to fire in the open pit. They were fired by lightning, but no one was injured. In this case, drilling is done on day-shift, the holes are loaded with electric primers in the evening, and the blasting is carried out at daybreak the next morning. The blast was fired by lightning in the middle of the night, and no one was in the vicinity. Near North Bay, Ontario, in the course of some construction work, men narrowly escaped serious injury when lightning set off a row of primed holes.

I believe that our operators are very careful to avoid the connecting up of electric blasting wires in a storm, but in two fatal accidents which have occurred in this district as a result of induced currents caused by lightning, no one had previous notice that a storm was imminent. In both cases, the sky was cloudy, and it had rained to some extent, but the sudden lightning discharges came without warning. This evidence was checked with the power company's substation records, and as you know, their instruments record even minor surges.

There is very strong evidence to indicate that the induced charges were led underground by the hoisting cables. A cable stretching from the drum of a hoist over the head sheave offers an ideal collector, i.e., condenser, as it is not grounded to unlimited capacity. Also, in case of a nearby discharge, it would pick up stray currents by induction and transmit or create secondary induced currents in parallel conductors. In view of the many and severe storms in this district, I favour the following practice:

When the explosives and electric primers have been delivered to the shaft bottom, the bucket shall be rung up to the blasting set. The men will then load the holes, and connect-up the wires between holes. When completed, they will ascend to the blasting set via the ladder, the last man unreeling the lead wires. When they reach the blasting set, they will test their circuit, and connect up to the blasting wires as in ordinary practice. If a chain ladder is used, it would be advisable to hang this ladder in a part of the shaft as far as possible from the hoisting compartment and the blasting wires; a wooden ladder would be preferable.

The suggestion contained in the above paragraph would, I believe eliminate the danger from unexpected lightning discharges. Of course, handling blasting caps during an electrical storm is clearly dangerous.

* * *

The details of this Shenango incident were as follows: Four "jump" holes had been drilled in an ore bank ahead of a shovel for the purpose of blasting the ore. These holes were about 30 feet deep. The blasters had placed one stick of dynamite with an electric blasting cap attached in each hole, which was the customary practice at that time in "blowing out" the holes preliminary to placing the regular charge of powder used in blasting the ore.

These four holes were not wired together. The ends of the blasting wires were lying upon the ground under a rock at the collar of each hole. The ends were not twisted together, which is our practice today in order to close the circuit and guard against stray currents and premature explosions.

While the holes were thus charged with one stick of dynamite each, an electrical storm came up during which the blasters and others in the pit sought shelter from the rain. When the men returned to the holes they discovered that all four sticks of dynamite had been discharged, presumably by lightning, although no one heard any definite report. No one noted that any particular flash of lightning struck in the open pit, but there was much lightning accompanying the storm. No one was injured.

We are unable to find any other instance of premature blasts at our properties due to lightning. It is the general rule today not to charge holes during an electrical storm.

With Cordeau fuse this danger of blasts being set off by lightning is minimized since no electric blasting cap is attached to the fuse until immediately before the blast, and this is not done if the weather is stormy. In ordinary electric blasting the ends of copper lead wires are always kept twisted together until the blast is ready to be set off, in order to guard against stray currents.

* * *

Replying to your letter of August 10, would advise that we have had no accident experience with reference to lightning setting off blasts prematurely at our operations at Calcite. We do, however, discontinue all loading and the handling of dynamite during electrical storms.

When I was in Tennessee in charge of the construction of the original dam on the Ocoee River, we did have two blasts in connection with our operations there which were set off by lightning. Fortunately, in the first case, none were injured, but in the second case two men were very seriously injured.

In this case the connecting wires had been distributed on the ground and connected to a few of the holes. They accumulated from the ground sufficient current to explode the dynamite.

Possibly these experiences have justified the very drastic rules which we have in use here to prevent the recurrence of these accidents.

The following reference regarding premature blasts which were attributed to lightning may be of interest to you:

The danger of charges primed with electric detonators being fired by lightning during a thunderstorm is well illustrated by an accident (78) which occurred at the Galloway Water Power Scheme, Kirkcudbright. From the evidence it would appear that charges amounting to 90 lbs. of Gelignite had been prepared and primed in the face of a tunnel 1,000 yards away from the entrance, when, whilst the men were returning to the firing battery, the charges suddenly exploded. At the time a severe thunderstorm was raging, and it is believed that lightning fired the charges. At the same moment a man, who was standing at the entrance of the tunnel with a spanner in his hand, received a shock which wrenched the spanner from his hand and caused him to fall. Eight men were injured as a result of this accident.9/

The chief coal-mine inspector of the Province of Victoria, Canada, wrote, in part, on July 21, 1938:

On July 5th, 1938, an explosion occurred in "B" mine, Michel Colliery, in the southeastern part of this Province, and caused the death of three men.

This colliery is situated in the Rocky Mountains, at an elevation of 4,000 feet, and is located in a narrow valley above which the surrounding mountains rise several thousand feet.

9/ His Majesty's Inspectors of Explosives: Fifty-eighth Annual Report, 1933, p. 20.

The measures are inclined from 10° to 30° and outcrop on the mountain above the mine which have been developed by means of a cross-measure adit drift and at present four mines are in operation, in separate seams, and may be considered as entirely separate mines except that their returns all join one common main return to the fan.

The intake of "B" mine is at the outcrop on the mountainside at an elevation of 600 feet above main adit drift and at a point some 4,000 feet, by course of air, from the main return.

The "B" seam is 5 feet thick and is all clean coal; the system of mining is to develop large pillars to a predetermined line and recover the pillars by a retreating longwall method. All the coal is machine-cut and conveyed to the cars on the main haulage roads.

This seam is quite dusty, but all the workings are well treated with lime dust, and the return air from this "B" mine shows, by analyses, variously from 1 percent to 1.25 percent CH_4 content and it is very seldom that CH_4 is detected by flame safety lamp tests in the working parts of the mine.

On the day of the explosion only some 17 men were underground, as it was an "idle" day; these men were engaged in repairs, moving machinery, etc., and were distributed as follows: 5 in "B" mine, 6 in No. 3 mine, 2 in the main return and 4 on the main adit tunnel.

Approximately 50 men are employed on dayshift in "B" mine, which produces 500 tons per day, and it is beyond doubt that had this explosion occurred during a working day many, if not all, of these men would have been killed.

At the time of the explosion (1:40 p.m.) there was an intense lightning storm, and some witnesses who were engaged on construction work outside the mine reported that they had seen a lightning discharge strike the immediate vicinity of the intake portal of "B" mine and raise a cloud of smoke; other men who were working close to the portal of the main tunnels were affected by lightning at the same instant.

There was no knowledge of an explosion at this time, but the above phenomena raised an alarm and on investigation it was discovered that an explosion had occurred in "B" mine.

At the same time three men working at different points in No. 3 mine reported to their fireboss that they had seen flashes of light running along the rails and making a moise like firecrackers; one man on an incline stated that he saw a light traveling up one rail for a distance of 250 feet towards him and appeared to die out 15 feet past him. None of these men experienced anything in the nature of an electric shock, but another man who was working on a 3-inch pipeline did suffer a shock. (I may say that there is no electrical equipment, with the exception of telephone and signal bells, underground in the Colliery.)

Unquestionably, the experience of the petroleum industry with lightning has been more expensive than that of the other mineral industries. In May 1939 a paper entitled "Possible Effect of Lightning on Underground Pipe Lines" was presented at the Annual Meeting of the American Gas Association and it appeared in the June 1939 issue of Pipe Line News. The following paragraphs were taken from the paper:

On August 20, 1938, our company experienced a major pipe-line break. The circumstances under which the break occurred and the characteristics of the pipe rupture did not combine to provide an acceptable solution of the exact cause or causes which actuated the break.

The weather conditions during the month of August will be briefly described, since it is entirely reasonable to assume that they may have had some influence, perhaps an important one, on what actually occurred.

The first four days of August were clear to partly cloudy with temperatures in the middle nineties. There was rain on the next three days ranging in daily amounts from 0.05 inch to 1.18 inches. This period was followed by 7 days of fair and warm summer weather. On the 15th, a rainfall of 1.58 inches was recorded and on the following day a light shower. The next 3 days were fair and warm. On August 20, the day of the break, the weather bureau recorded a rainfall of 2.83 inches. It is of special significance to note, according to a farmer who lived nearby, that a severe stroke of lightning occurred simultaneously with the pipe-line rupture.

The break occurred in western Iowa, about 7 miles northwest of Red Oak and 7.4 miles east of our nearest compressor station. The country in the vicinity of the break is glacial drift known as upland - in general, a gently undulating plan. The hills throughout the upland are smooth and rounded. The slopes are gradual and uniform and the landscape has a rolling appearance. The pipe rupture occurred on the top of one of these hills. The immediate field was under corn cultivation.

Probably more important than weather conditions surrounding a break such as that with which we are concerned, are the detailed facts of the construction of the line, the location of the rupture, and other contingent circumstances.

When the 24-inch line was laid in 1931, the composite type of construction was used; that is, two or three 33-foot joints of pipe were welded together to form a solid welded section. These sections were joined by a Dresser-type coupling. The trench was excavated to a nominal width of 32 indhes and a minimum depth of 5 feet, which provided a minimum cover of 3 feet.

The pipe was completely severed by the rupture. The reaction which immediately followed the initial force contained sufficient energy to turn a 39-foot piece of the pipe section end for end. This pipe came to rest about 50 feet from its original location in the pipe line. The remaining section of the pipe came to rest approximately 125 feet from its position in the line. This piece of pipe contained the 8° overbend.

Inasmuch as a severe stroke of lightning was reported to have occurred simultaneously with the pipe-line break, it was decided to investigate the probabilities of lightning as an influencing factor.

Our first efforts in this regard were directed toward a search on articles or discussions on the subject of lightning and its contributing influence on pipe-line failures. Inquiries were directed to the secretaries of the American Gas Association and the American Petroleum Institute. The Industrial Arts Index was also reviewed. We found three specific citations with direct bearing on the subject. The following will briefly describe each incident.

Mr. Fred M. Goodwin, vice-president of Distribution of the Boston Consolidated Gas Co., has related an experience which occurred in Boston in September 1903. This incident was reported in a letter dated September 27, 1938, to the American Gas Association. The construction of a 24-inch main had been completed but had not been placed in service. A 24-inch gate valve had been installed at the point of connection with the existing system. Two or three days following the completion of the line there was a severe thunder storm, during which lightning struck a drip stem; this resulted in blowing five lengths of 24-inch pipe out of the trench. The supposition is that the 24-inch gate valve did not make a tight shut-off, which permitted a leakage of gas into the newly completed section. A gas-air mixture was thus formed which was ignited by the lightning and resulted in the explosion.

The issue of the Gas-Age Record dated August 30, 1924, contains an article entitled "Lightning Destroys a New 20-inch Gas Main." The failure occurred on the night of August 6, 1924, at Worcester, Mass., during a terrific electrical storm. It was definitely determined that lightning had struck one or more times in the vicinity of the newly completed 20-inch cast-iron main and that 60 feet of the 20-inch pipe were damaged. The cast-iron pipe was completely shattered and gave the appearance of having been struck by a large stone breaker or steam hammer. The main had not been placed in service and was supposed to contain only air, with possibly some water. The article states that four theories were advanced as to what might have caused the pipe to rupture. First, the lightning stroke near the pipe may have caused a partial vacuum around the pipe, causing internal air pressure to rupture the pipe. Second, if the lightning struck directly over the pipe and passed through, it may have caused the air in the pipe to expand, and the expanded air may have caused the failure. Third, the pipe was laid on a slope, and moisture and water could have accumulated in the lower end of the pipe. A bolt of lightning may have converted the water into steam and the resulting pressure may have been sufficient to rupture the pipe. The fourth theory was that the pipe could have contained an explosive mixture which was ignited by the lightning.

An issue of the Kansas City Power & Light Co.'s house organ, "Public Service," contains an article entitled "Lightning Puts Transmission Line Out of Commission," written by Mr. D. P. Hartson, operating manager, Pittsburgh & West Virginia Gas Co. and Equitable Gas Co. The article states that on March 13, 1933, lightning struck a 16-inch gas transmission line carrying a pressure of approximately 140 pounds per square inch. The line was installed over an unusually high ridge of ground - the second highest in that vicinity. The line had a cover of 2-1/2 feet and had been relaid in October 1932; therefore, the ditch undoubtedly was comparatively soft. A telephone line paralleled the pipe line, and at the point where the pipe was ruptured there was a guy wire which came within 2 feet of the pipe. A jagged hole approximately 10 inches by 18 inches, was torn in the pipe. The edges of the hole were definitely turned in, and the damaged pipe showed a perceptible deflection. There were no evidences of fusion or of heat on the pipe.

Representatives of the Duquesne Light Co., the Westinghouse Electric & Manufacturing Co., and the General Electric Co. were consulted regarding the part lightning may have contributed toward the pipe rupture.

Mr. C. F. Fortescue (deceased), Consulting Engineer of the Westinghouse Electric & Manufacturing Co., together with his assistant, made a very careful study of the pipe and other conditions surrounding the strike. The studies which he made and the conclusions drawn seem to give ample confirmation of the theory that the failure was caused by the pressure created by a lightning discharge through the earth and partly confined by it. The above incident is quite analogous to our own break.

In a further effort to obtain more information on the phenomena of lightning, we consulted a number of technicians who were well qualified to discuss this subject. These men were representatives of General Electric Co., Westinghouse Electric & Manufacturing Co., Western Railroad Supply, U. S. Bureau of Standards, U. S. Weather Bureau, Armour Institute of Technology, and Kansas City

Power & Light Co. Several theories and opinions were advanced as to the influence lightning would have in the destruction of pipe to which we have referred. Some of the engineers were of the opinion that it was possible but not probable for lightning to have sufficient force to rupture such a steel pipe. Others were of the opinion that the lightning stroke could have had a current magnitude of 200,000 to 250,000 amperes, and since it would dissipate itself in microseconds of time, it would be sufficient to cause destructive distillation of the cell structure of the earth and thereby develop enough pressure to destroy the pipe in a manner similar in some respectis to piercing the pipe with a projectile.

It may be well to review a few of the phenomena of lightning and its destructive forces. It is generally accepted that when lightning strikes a tree, the tree is splintered from the internal pressure developed by the formation of steam from the moisture in the tree. It is further possible that under the high current intensity and potential gradient of a lightning charge, some of the material itself is decomposed or distilled with the formation of gaseous products which develop a high pressure.

It is known that when lightning strikes an insulated copper wire, the wire will completely volatilize and disappear. There will be no indication of burned or fused metal. The insulation will remain intact with no appearance of having been heated.

The June 12, 1936, issue of Science contains a very interesting report of a lightning stroke which occurred near Dodge, Neb., on June 24, 1935. The families who lived in the vicinity reported a lightning stroke of explosive intensity. A few days later a hole was found in the earth in a corn field. The hole was investigated and was found to measure 8 inches in diameter at the surface. The hole extended downward 8 feet almost vertically with an average diameter of 8 inches and then became smaller for the next 7 feet and varied somewhat from the perpendicular. At a depth of 15 feet the diameter had been reduced to about four inches and the main hole branched out in three directions into 2-inch holes which followed for 3 or 4 feet horizontally into the earth. The clay showed signs of fusion at a number of points, and the inside of the hole had a corrugated appearance as though moist clay had been forced violently back by high pressure. It is known that when lightning strikes sand or sandy soil, fused sections will result which are known as lightning tubes or fulgurites. These statements represent interesting examples of the heat and action of the lightning stroke.

The Oil World of Sepbember 1939 has an excellent article entitled Fire Prevention, Protection Development in the California Oil Industry (pp. 3-7), and the following paragraphs taken from it indicate some of the problems of the petroleum industry due to lightning as well as other causes of fire:

It takes a serious loss to create a sense of future caution. Prior to 1920 no such loss had occurred in the oil industry on the

Pacific Coast and because of it no great amount of thought had been given either to scientific fire protection or to any far-sighted program of fire insurance. There had been some fires, but they had been isolated and had involved neither large values nor great public concern. True enough, when chemical fire-fighting equipment became a merchantable commodity through the introduction of licorice as a stabilizer of chemical foam, the Pacific Coast oil companies followed the lead of Standard of California in buying and installing solution systems, particularly for their refineries and large tank farms and metropolitan bulk marketing stations. But this was stop-loss defense rather than fire prevention.

During the next year, 1924, a group of wooden-roofed steel oil tanks on Monterey Bay was ignited by lightning. This fire spread to other oil properties and caused a loss of more than a million dollars. History repeated itself inasmuch as the company involved became very fire conscious and immediately organized a fire protection department.

There followed three other fires, involving some seven large steel tanks, all with wooden roofs, and again the ignition cause was lightning, probably through induction, since direct hits were not seen. It became more and more evident that wood-roofed storage of low-flash crude oils, either in steel tanks or earthen and concrete-lined reservoirs, presented a fire hazard from lightning that differed radically from the lightning hazard to other types of structures. Meanwhile, two other companies became converted to the fire-protection idea.

It was natural enough that the engineers who had been assigned by these several companies to the newly organized fire service should get together. One of the first activities was to study forms of lightning protection, and it is a fact that in 1925 plans were well under way for the installation of lightning towers and Faraday grids for oil-reservoir protection under the direction of Messrs. Frank Peeke and E. R. Shaffer. The interest in this form of protection was accelerated by two great lightning fires in the fall of that year each involving a crude oil reservoir.

Then on the morning of April 8, 1926, two 750,000-barrel reservoirs blew off their roofs simultaneously at San Luis Obispo, Calif., and an hour later another of the six reservoirs followed suit. In the ensuing fire all six reservoirs were destroyed along with 15 steel, wood-roofed tanks in the same farm. California, which is practically lightning-free, had produced the greatest oil fire of all times.

I wish that the story might end here, but unfortunately this was not bad enough, for on the morning after the ignition at San Luis Obispo, the same freak or unusual storm reached Brea, Calif., 250 miles to the south, and there repeated on another tank farm of the same company. Here three reservoirs and a small refinery were destroyed. There was one other reservoir-lightning fire 3 weeks later, since which time the record has been perfect on all protected risks.

It is needless to say that the five oil companies involved in the fires that have been mentioned have never lost their interest in fire protection. Lightning protection has become standard practice. It is however curious to note that the other companies on the Coast have not followed their example in setting up fire engineering departments. It is the group which went through the great fires of 1923 to '26 that are today carrying the fire protection program.

It is pleasant to be able to say that so far as the last ten years are concerned, the Pacific Coast and particularly the major companies, have profited by the experiences of the past and that the whole subject of fire protection has been given reasonable backing by most companies. Lightning protection, elimination of wood roofs and better housekeeping has helped. Losses have been small and as a result there has been time to consider the problems of community protection.

PROTECTION AGAINST INJURY OR DEATH DUE TO PREMATURE EXPLOSION

In mines and quarries, precautions should be taken to prevent as far as possible any chance of premature explosion due to lightning. Short-circuiting of the lead wires is a primary precaution. In some open-pit mines, it is now the general practice not to charge holes during the approach or progress of an electrical storm. In underground mines, however, this would not be practical.

In mines using electrical equipment, feeder cables from the surface are a necessity. Such feeders should be equipped with modern-type lightning arresters near the point of entry to the mine. These arresters should be examined and tested frequently, not only to insure that the arrester is functioning properly, but to keep a check upon the ground resistance and to maintain it at a low value. Low values of ground resistance are imperative, if maximum protection is to be obtained.

The question is frequently asked as to what constitutes a good ground; the better the ground, the better the protection, hence, the best ground is none too good. Lightning discharges or surges run into thousands of amperes, and a high ground drop can put the arrester at such a high discharge or ground voltage that it loses its effectiveness. A 5,000-ampere surge through a 30-ohm ground would produce a 150,000-volt drop in the ground only.10/

Care should be taken to see that lead wires and shot-firing lines do not come in contact with rails, air or water lines, and at no time should the

10/ Pearce, C. T., and Allen, R. E., Lightning Dangers to Coal-Mine Distribution Systems Minimized by Protective Devices: Coal Age, vol. 42, No. 9, September 1937, pp. 59-60; No. 10, October, pp. 55-58.

bare wires be allowed to contact the rib, roof, or floor after the holes have been charged.

Lightning-arrester grounds should not under any circumstances be connected to rails, tracks, or pipe lines entering the mine.

To the extent that it is possible to do so, the personnel in a mine should avoid contact with rails, pipe lines, or electric switches and apparatus when it is known that a lightning storm is in progress on the surface.

PROTECTION OF EQUIPMENT

Electric equipment and transmission lines are particularly vulnerable to damage from lightning. Disturbances in power systems due to lightning can, in general be placed in two classes:

(1) Direct stroke of lightning.

(2) Surges resulting from lightning discharges in proximity to the line.

Direct strokes of lightning vary in intensity; the lesser ones are, nevertheless, of great severity. Pearce and Allen[11] describe it as follows:

> Lightning has much the characteristics of a prize fighter's punch. A direct hit is like a "sock to the jaw" and can be a knock-out unless the recipient is built to take it. The shock, however, goes through the system. With arresters installed, the stroke is like a glancing blow - part of the effect is "drained off" so that the peak is not so great, even though of the same steepness. Complete protection for equipment such as rotating machinery requires protective apparatus which will also slope the wave front so that the blow becomes more of a push, even though of the same magnitude, and against which the electrical equipment can, so to speak, brace itself.

Electrical equipment requires the protective functions of both lightning arresters and capacitor equipment to reduce the steepness of the wave front. To quote again from Pearce and Allen:

> Any equipment with multi-turn circuits presents the known fact that, when a surge is impressed upon it, the voltage will not distribute evenly throughout the circuit but will depend on the number and arrangements of the turns and the steepness of the front of the surge.

In one case where a 300-kilowatt motor-generator set was damaged frequently by lightning, three single-phase lightning arresters of the ceramic-disk type were installed in the pit beneath the motor-generato set. A 3-phase oil-filled capacitor unit was also installed in the pit and connected across the terminals of the 2,300-volt motor. This combination effectively eliminated further damage from lightning at this location.

11/ See footnote 10.

For the protection of direct-current circuits the capacitor-type arrester, though more expensive, is likely to be superior to the multigap arrester. The capacitor-type not only has a much lower voltage ratio, but it is applicable to circuits up to approximately 4,000 volts. For this reason, it is particularly adapted for use with direct-current machinery or machines with weakened insulation.

WHAT TO DO

A resume of the foregoing would indicate that the following procedure may reduce the danger of injury and death from lightning:

During the progress of a lightning storm,

(1) Get under shelter when the storm comes. Do not stay out in rain. The larger the house or barn the better the protection.

(2) Avoid shelter under isolated trees. The middle of a dense forest is fairly safe. Avoid the foot of a pole, mast, or tower.

(3) Avoid an open space, such as a beach, swimming pool, fishing pond, baseball field, golf links, or pasture.

(4) Leave hilltop or ridge. Head for the valley or the base of a cliff. A cliff is relatively effective shelter.

(5) Leave a small camp cottage, small shed, or small open barn for a larger building. In a large building stay downstairs. Choose a place near the center of the room. Avoid windows. Stand away from stoves or pipes. Shun the fireplace.

(6) If you are driving an automobile when the storm comes up, remain in the car with windows almost closed.

Victims of lightning stroke often can be resuscitated if proper treatment is given in time. Injury and death from lightning result from electric shock, and the indicated treatment is artificial respiration and treatment for physical shock.

Lightning, like electricity from a power system, causes shock by paralyzing the nerve centers that control breathing or by stopping the regular beat of the heart. In severe cases, burning of the body tissues is probable. Artificial respiration should be given immediately.

ARTIFICIAL RESPIRATION[12]

Artificial respiration is a method by which normal respiration is imitated by manual movements to restore breathing. In many conditions where breathing has ceased or apparently ceased, the heart action continues for a limited time.

12/ Bureau of Mines, Manual of First-Aid Instruction: 1940, pp. 52 and 53.

If fresh air is brought into the lungs, so that the blood can obtain the needed oxygen from it, life can be sustained. That can be accomplished in a great number of cases by artificial respiration. Every moment of delay is serious. As the breathing may be so faint that it will not be detected by the layman or first-aid man, it is advisable that artificial respiration be started immediately, even if the person seems dead. Artificial respiration should be continued without interruption until natural breathing is restored, or until a physician declares that the patient is dead. Persons have been resuscitated after as long as 72 hours of artificial respiration. If natural breathing stops after being restored, give artificial respiration again.

TREATMENT OF PHYSICAL SHOCK 13/

Shock is a dangerous condition that should be given prompt attention, and medical aid should be obtained as soon as possible. Procedure for handling cases of shock is given in detail in the Bureau of Mines Manual of First Aid Instruction.

It is of major importance in treating shock to attempt to restore the body warmth by adequate covering over and under it, heated objects within the covering, and warm drinks, if the patient is conscious. Next to reestablishing normal body temperature by warmth, the position of the patient plays an important part in caring for shock. If the patient is lying down and the head is on a level with or lower than the feet, the flow of blood to and from the overworked heart is greatly aided.

As long as evidence of shock is present, shock treatment should be continued. Patients in a state of shock tend to relapse, even after their condition has greatly improved. Relapse should be watched for and combated by renewed shock treatment. After he has recovered from shock of even short duration, the patient should be kept lying down and quiet so that as little strain as possible is placed on the circulation and heart action.

AVOIDANCE OF DAMAGE BY LIGHTNING

Preventive measures covering the avoidance of premature explosions and damage to equipment and buildings due to lightning should include the following:

(1) Strict adherence to codes and regulations established for safe blasting procedure and the prevention of accidents.

(2) Careful supervision of blasting methods and frequent dissemination of available knowledge on the subject.

(3) Installation and maintenance of lightning arresters and electrostatic capacitors at strategic locations on power systems, and overhead ground wires on transmission lines.

13/ See footnote 12.

(4) Frequent checking of insulation values on rotating machinery and transformers and the maintenance of such insulation at high values.

(5) Provision and maintenance of low-resistance grounding connections for lightning arresters and for the frames of rotating equipment and transformers.

(6) Installation and maintenance of lightning rods and overhead ground wires on isolated buildings of nonmetallic construction.

A draft of a radio presentation on the subject "Protection Against Lightning by the Underwriters' Laboratories, Inc., had some interesting statements, as indicated by the following abstracted dialogue:

DUDLEY: Are there any figures to prove the value of lightning protection?

MANNING: The records are full of proof. Eight years ago, 6,000 grain elevators in the Prairie Provinces of Canada were equipped with approved lightning-protection systems. Each elevator containing 50,000 bushels of grain was insured for $25,000. Before these elevators were protected, there had been an average yearly lightning loss of $160,000. Two years after the lightning rods were installed and inspected, not a dollar's lightning loss had been sustained. And today, 8 years later, we have still not had a report of any lightning damage to those elevators.

ALCOCK: The entire project was more than paid for by the savings effected in a few years.

DUDLEY: That's remarkable! And to date (I've been doing a little mental arithmetic), the protection of those elevators represents a saving of nearly a million and a quarter dollars.

WOOD: The record in one midwest State shows that over a 2 year period, 503 buildings without lightning protection were struck, causing a loss of 81,060,000. In the same period only 28 protected buildings were hit, and the loss was about $87,000.

On the other hand, an inquiry as to lightning-rod protection for surface explosives magazines was addressed to one of the best-informed experts of one of the major producers of explosives in the United States, and brought forth the following reply:

> We agree that a lightning rod, properly installed and properly maintained on a dynamite magazine, should offer some protection. On the other hand, a lightning rod, if not properly installed or cared for, makes the condition worse than if no rod had been installed at all. In view of the fact that dynamite magazines are almost invariably in isolated locations, the magazines themselves

do not receive much attention, and we feel sure that lightning rods would not receive proper care. Furthermore, to be correctly installed, a lightning rod should be attached to the building rather than at a distance of, say, 18 feet as is specified in your inquiry. Our company has never installed a lightning rod on any field magazine; and so far as our records and memories go back into the past, we have never lost a field magazine due to lightning. Under the circumstances, we recommend definitely against the installation of lightning rods.

An article containing some discussion on lightning protection in the July 1941 issue of Coal Age, page 55, had the following statements:

Generally speaking, lightning-proof lines are possible. The degree of lightning protection is limited only by the money which can be economically spent for it. Proper grounds for lightning arresters are very important. Line-type arresters, station-type arresters, capacitors and overhead ground wires can be added in any combination. An ample ground connection of low resistance is most important. Mine rails for lightning-arrester grounds have proved excellent electrically, but their complete safety is still debatable. When possible, the National Electrical Code suggests a separate ground from the rails.

Since the average value of mine-rail resistance to ground varies from 1 ohm to about 20 ohms, tests should be made in each case. Mines should have at least on alternate ground connection for each substation where rail resistance is high. Where bore-hole casings or water lines are available, the problem is simplified; where an artificial ground must be constructed, care must be used.

Larger wires - 4/0 is not too big - for grounding and better terminal connections should be used. Brazing to the frame if vibration is present may be desirable to obtain good contact. Inspection of the ground connections at frequent intervals is recommended. Tests should be made every year. Use of d.c. capacitors or suitable arresters across the terminals of machines increases protection. The capacitor also aids where flash-overs are the tendency.

Temporary ground connections for power conductors when men work on the lines should be standard practice. Static electricity can be drained to a good, carefully made, temporary ground. Care should be used in grounding lines so that men do not work in positions where a drop in potential occurs across their bodies.

Avoid metal fences around high-voltage equipment unless there is an exceptionally good ground connection. Before using the steel framework of any building for grounding exposed metal surfaces of electrical equipment, it should be determined whether the steelwork is at ground potential; if not, it should be grounded to prevent shock.

Since in the d.c. mine circuit the negative is grounded with current return in the rail as standard, positive wires should be kept insulated, negative wires grounded, and rails well bonded. Grounding of rails frequently is not perfect, since they rest on rocky soil and mine ties. As an added safety precaution, a supplementary ground connection, such as a water system, borehole casing or artificial ground, is desirable if the mine rail is to be counted on as an absolute grounding medium.

The lightning hazard has unquestionably been reduced as compared with the conditions in effect one, two, or more decades ago; however, losses of life and of property due to lightning continue to occur.

CONCLUSION

This paper presents some information on the effect of lightning on the mining industry, and it will be noted that both surface and underground work is affected and that, while premature detonation of explosives is one of the main hazards in the mining industry due to lightning, it is by no means the only harm to the industry from this cause.