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THE USE OF PERMISSIBLE EXPLOSIVES

BY

J. J. RUTLEDGE

AND

CLARENCE HALL

WASHINGTON

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PREFACE.

A publication entitled "A Primer on Explosives for Coal Miners," which was reprinted as Bureau of Mines Bulletin 17, contains a general account of the properties of the explosives commonly used for blasting coal, a description of the devices used for firing such explosives, and some general directions on the use of explosives. The present bulletin is printed as a supplement to Bulletin 17 and is intended primarily for coal miners, especially for those working in fields where inflammable gas or coal dust may cause disastrous mine explosions. The bulletin is issued by the Bureau of Mines in the hope that it may prove helpful in lessening accidents due to the use of explosives, and in particular may aid in preventing mine explosions, many of which have been caused by the use of improper explosives.

The authors wish to acknowledge the courtesies shown them by various coal-mining companies in the course of visits to mines at which permissible explosives are used. In particular, they wish to thank the officials of the Consolidation Coal Co., Fairmont, W. Va., for cooperation in obtaining photographs to illustrate the methods of using explosives, and the Tennessee Coal, Iron, and Railroad Co., Birmingham, Ala., for the material used for the illustrations showing the arrangement of shot-firing wires in headings and rooms.

THE USE OF PERMISSIBLE EXPLOSIVES.

By J. J. Rutledge and Clarence Hall.

INTRODUCTION.

Explosives used in coal mines.

Many of the fatal accidents in coal mines have resulted from the use of explosives for breaking down the coal. These accidents have resulted both from the use of explosives that were not suitable and from the careless or improper use of suitable explosives.

Investigation has shown that one of the commonest causes of disastrous explosions in the coal mines in this country has been a blown-out shot of black blasting powder or dynamite. The dangers that attend the use of these explosives were perceived several years ago, and in consequence the attention of powder manufacturers was directed to the production of explosives that would be less liable to ignite inflammable gas or dust. The manufacturers have been so successful in their efforts that it is now possible to obtain explosives which yield much shorter and quicker flames than black blasting powder or dynamite, and hence are much less dangerous to use in fiery or dusty coal mines.

Government tests of explosives.

To find out which of the many grades of short-flame explosives have the qualities that render an explosive most effective and least dangerous for mining coal, the United States Government established a testing station at Pittsburgh, Pa., in 1908. This station is now under the charge of the Federal Bureau of Mines. Before the station was opened a statement of the requirements that the explosives in question would have to satisfy was drawn up and sent to manufacturers. A number of these sent explosives to be tested, and on May 15, 1909, a list of the explosives that had passed the tests was published. Since that date other brands of explosives have been tested and three more lists have been issued. The latest list, published in Miners' Circular 2, Bureau of Mines, contained the names of no less than 71 explosives that had passed the tests prior to January 1, 1911.

These explosives are termed permissible explosives and are thus defined: An explosive is termed a permissible explosive when it is similar in all respects to the sample that passed certain tests by the Federal Bureau of Mines, and when it is used in accordance with the conditions prescribed by the bureau.

Permissible explosives.

The tests that the explosives must pass and the conditions under which they are deemed permissible are given in two publications, Bulletin 17 and Miners' Circular 2, of the Bureau of Mines.

All the explosives named in the published tests of permissible explosives are short-flame explosives; but there are short-flame explosives that have not yet satisfied the requirements of the Bureau of Mines and hence are not permissible explosives.

Permissible explosives are now used to a considerable extent in the coal mines of Pennsylvania, West Virginia, Alabama, Colorado, and to a less extent in those of southern Illinois, Oklahoma, and other States. Their use increased greatly during the last half of the year 1909, the quantity sold in that period being nearly three times as great as that sold in the whole of 1908. This rapid increase is believed to have resulted in part from the publication of facts about these explosives by the United States Government and in part from repeated public demonstrations at the Pittsburgh station which proved that shots of black blasting powder ignited the dust of bituminous coal, but shots of permissible explosives did not.

Increased use.

In order to find out how fast the use of better explosives was increasing, the Government sent inquiries to various makers of explosives in this country. In reply to these inquiries the manufacturers gave their yearly sales of short-flame explosives for the years 1900 to 1909. From these statements two tables have been prepared. The first table shows the quantities sold during each year from 1900 to 1909. The second gives the quantities sold during the first and second halves of the year 1909 and names the different coal fields in which the explosives were sold that year.

Sales of short-flame explosives.

Yearly sales of short-flame explosives in the United States.

Year.	Pounds.	Year.	Pounds.
1900		1905	1,031,300
1901		1906	1,533,575
1902	11,300	1907	2,095,244
1903	288,661	1908	2,108,610
1904	608,270	1909	a 8,942,857

a Includes 8,598,027 pounds of permissible explosives.

Quantity of permissible and short-flame explosives sold in different coal fields in 1909.

Coal fields.	From Jan. 1 to June 30.	From July 1 to Dec. 31.	Total.
	Pounds.	*Pounds.*	*Pounds.*
Pennsylvania anthracite	329,330	564,964	894,294
Northern Appalachian	2,132,875	3,843,750	5,976,625
Southern Appalachian	618,900	816,050	1,434,950
Eastern interior	750	6,205	6,955
Western interior	82,500	171,975	254,475
Rocky Mountain	12,700	134,000	146,700
Pacific coast	29,610	199,248	228,858
	3,206,665	5,736,192	[a] 8,942,857

[a] Includes 8,598,027 pounds of permissible explosives.

The first table shows that the total production of short-flame explosives in the years 1902 to 1908, inclusive, was 7,676,960 pounds, and that the production in 1909 was 8,942,857 pounds; in other words, the production of these explosives in the single year 1909 exceeded the entire production in the United States up to January 1, 1909, by 1,265,897 pounds.

Sales of permissible explosives.

The second table shows how rapidly the use of short-flame and permissible explosives is increasing in the different coal fields. The table, in a way, also shows how coal mining is being made safer for the miner, because each pound of these short-flame explosives used takes the place of at least a pound, and probably much more than a pound, of the more dangerous black powder. The demand for the permissible explosives is shown by the fact that in 1909 the total sales of such explosives in the different coal fields amounted to 8,598,027 pounds, or more than 96 per cent of the total sales of the short-flame explosives in that year. The returns received from the manufacturers indicate that the sales of permissible explosives for the year 1910 reached 12,000,000 pounds.

Classes of permissible explosives.

Permissible explosives may be arranged in four classes that are based on the nature of the substances used in making the explosives and the proportions used of these substances. These classes are: Ammonium nitrate, nitroglycerin, nitrostarch, and hydrated explosives. Some of the manufacturers of permissible explosives make several grades of each of these classes, each grade being suited for some of the varying conditions that exist in the coal beds of different regions. It is possible by experiment to make a permissible explosive suitable for shooting any coal that is properly undercut or sheared, just as it is possible to get a grade of black blasting powder suitable for blasting the same coal. Manufacturers are trying to make explosives of the "permissible" type that will meet the requirements in each of the coal fields in this country, that will do any kind of blasting as well as black blasting powder, and that will do it with less danger to the miner. In these efforts the manufacturers have already made good progress.

Most permissible explosives have the general character of "high" explosives, and all are entirely different from black blasting powder in composition and action. They give a shorter flame, explode more quickly, and are much more powerful. To use them properly the miner must allow for their greater quickness and strength.

METHODS OF USING PERMISSIBLE EXPLOSIVES.

The authors of this bulletin visited many coal mines in which permissible explosives were being used, and noted the ways in which the explosives were employed to shoot beds of coal that differed in hardness, in height, and in the character of the joints, partings, etc. They gave careful attention to the ways in which holes were placed and charged and the methods of firing shots.

PLACING AND CHARGING OF SHOT HOLES.

Position of shot holes.

Coal beds vary greatly in thickness and in other features from place to place, so the best position and arrangement of shot holes can not be the same in all coal fields. In some districts, shots of permissible explosives must be placed 2 feet from the roof and ribs in order to give best results, whereas in other districts the shots must be placed 6 inches from the roof and ribs. The "lift" of the hole (the angle the hole makes with a horizontal plane) must also vary in different fields. In some districts the holes are driven nearly flat and in others they make an angle of 30° with the horizontal. However, holes for permissible explosives never require as great a lift as do holes for black blasting powder, and level holes that "cut out" horizontally give better results than holes with considerable lift. Generally all holes are driven parallel to the ribs, but if a face is uneven one drill hole may be driven at an angle with the rib in order to square up the face. The holes should never be drilled on the solid, and should never be driven any farther than the undercutting or shearing extends.

Care in placing shots.

In using permissible explosives the miner should take all the precautions that a careful miner would take in using black powder. The permissible explosives are much stronger, bulk for bulk, than black powder, and they will not give the best results unless they are used with judgment. From their observations in many coal mines, the writers of this bulletin are convinced that permissible explosives work to best advantage and yield the largest proportion of lump coal when the face is undercut properly and then blasted by several successive shots. It is much better and safer to use a number of small shots than a few large ones. As a rule, increasing the number of shot holes, up to a certain limit, increases the proportion of lump coal. In the best practice, all holes are so drilled as to take every possible advantage of bands or partings in the coal bed, and each shot is fired and the coal is loaded out before the next shot is fired.

Size of cartridge.

Each permissible explosive is sold in cartridges that are always made of a certain diameter and length. Consequently the miner can tell exactly how large the drill hole must be to give good results from a charge of each explosive, and can keep his coal auger at a certain definite gage.

Methods of charging holes.

Some permissible explosives are sold in cartridges that are too large to be inserted in the drill hole. If the diameter of a cartridge is too large the cartridge is usually slit and the explosive is removed and put in a loosely rolled paper case that is just large enough to fit the drill hole. To make a new case in this way takes time and delays the miner in preparing his shots. This procedure is not recommended, because tests at the Pittsburgh testing station show that any change made in the kind or quantity of paper in the case causes a change in the gaseous products of explosion and, in some cases, in the safety qualities of the explosive. If the cartridges supplied have considerably less diameter than the drill hole, some miners slit the cartridges into halves lengthwise and tamp the separate pieces tightly into the hole. This method is followed where the coal requires a quick explosive. If a slower action is needed, it may be had by leaving an air space in the drill hole about the cartridge.

Because of the delay caused by making new cartridges, the miner usually prefers explosives in cartridges that fit the drill hole and can be used just as they are supplied. If the cartridges fit the hole snugly, no time is lost in charging shots, whether miners or shot firers do this work.

Clay for stemming.

Moist clay made into "dummy" cartridges of slightly smaller diameter than the drill holes is employed for stemming at most mines where permissible explosives are used. This clay is either dug outside the mine, brought in by mine cars, and left along the entries at points within easy reach of the miners, or it is dug inside the mine, from the clay bed underlying or overlying the coal, and distributed along the entries.

Dangerous stemming.

At some mines the writers saw shots tamped with coal spalls, but the practice is not recommended. Coal cuttings and fine dust made by the cutting machine or the auger have been used for stemming, but their use is dangerous. Even if they are wet, the relatively cool flame of a permissible explosive may ignite them.

Tamping bars.

Wooden rods that fit the drill hole snugly should always be employed as tamping bars. Iron or steel rods should never be used, and even copper-tipped bars are not to be recommended.

Tightness of tamping.

The tightness of the tamping for permissible explosives varies considerably in different fields. Some coals seem to break best if the stemming is tamped tightly; other coals break best if the stemming is packed loosely near the explosive and tamped tightly throughout the rest of the hole. If an explosive is too quick acting for a certain coal, many miners put in a plug of soft, tough clay so as to leave a small air space between the explosive and the stemming. Such an air space lessens the charging density; that is, it makes the charge smaller in proportion to the size of the chamber. The effect of the air space is to reduce the shattering action of a quick explosive enough to suit the particular coal being blasted. If an air space is left about the charge, the miner or shot firer must take great care to ram firmly the outer part of the stemming.

Use of air space.

Permissible explosives and black powder at the same working face.

At several mines the writers saw that the first or opening shot, on the success of which all the following shots in the face depended, was fired with black blasting powder, because this explosive acts more slowly than the permissible explosives used. In these mines the miners had the option of using either black powder or permissible explosives in the opening shot. To use two explosives in such a way is not good practice. There is too great a chance of the explosives getting mixed; and if different explosives are used in the same drill hole fires are likely to result. Aside from the danger of fires, black powder should not be used in bituminous mines that are dusty or in mines that make any gas (methane) at all, for in such mines shots of black powder may start explosions, no matter how well the shots are placed and charged.

FIRING OF SHOTS.

Electric shot firing.

In those mines that use the permissible explosives in the best and safest ways, shot firers are employed, and the shots are exploded by electric detonators.[a] Each shot firer carries with him on his rounds a number of electric detonators and a firing machine. In the interior and far western coal fields it is the rule, and in the majority of the Western States it is required by law that shot firers make their rounds only after the miners have left the mine. In some of the mines in the Appalachian fields (Pennsylvania to Alabama) it is customary to fire the shots during the day shift. There the shot firer's round of the places is so timed that when

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[a] See pp. 29–32 for a more detailed description of electrical shot firing.

he arrives at each working place the miner has generally prepared the hole, has placed the stemming and the explosive near the drill hole, and is waiting for him. The shot firer examines the face, estimates the quantity of explosive needed, fits the electric detonator to the explosive, and then inserts and tamps the charge. The miner usually helps to load the stemming. As soon as the tamping is done, the detonator legs are properly connected to one end of a piece of double leading wire or cable from 75 to 100 feet long, and the farther end of the cable is carried back to a crosscut or other convenient place out of danger from the shot. Then, after everyone has left the working place, the wires are connected to the firing machine and the shot is fired. This plan, if carefully followed, greatly reduces the dangers of accidents from shot firing during a shift. Generally there is a loss every few days of a foot or two of leading wire, due to the breakage of the ends of the wires, but this loss is too small to be considered.

At the mines where this plan is now in use, the number of shot firers needed is about one for each 200 to 300 tons of run-of-mine coal per day, provided the coal has been properly undercut before shooting.

Advantages of system.

An advantage of the system of shot firing by electricity is that the operators usually furnish the electric detonators, and the detonators they supply are more apt to be uniformly good than those bought by the miners at different stores. Another advantage is that the operator knows that the detonators are of the right strength—a most essential matter—and can fix the responsibility if poor detonators are used.

Two charges in a hole.

In one mine visited, shot holes with extra heavy heels were sometimes loaded with two charges, and these charges were fired in series. For example, in a 6-foot hole with two sticks of permissible explosive at the bottom, half a stick was placed at a point 2½ feet from the mouth, and the remainder of the hole was tightly tamped. The legs from the electric detonators were arranged to connect the charges in series; that is, one after the other. When the shot was fired, the extra charge blew off the heavy heel. This practice is dangerous, because if the outer detonator is defective and does not explode, and the inner one is good and explodes, the outer charge will be blown out of the hole, and its flame may ignite gas or dust. Wherever shots are so placed that they depend one on the other for relief, the best practice demands that the single holes should be fired separately in their proper order.

Danger of practice.

Use of fuse and detonator.

Ordinary fuse has been and still is generally used for firing such shots as the miner himself fires. Fuse and detonator are also used in some mines in which shot firers are employed. Where fuse is employed in firing permissible explosives, the common practice is to load and fire the holes shortly after they are drilled. Although convenient, the practice is not recommended for use in coal mines in which inflammable gases occur. The chance of an explosive not detonating properly is always greater with fuse than with electric detonators. The chief danger, however, is in the ignition of gas. The naked flame used to light the fuse, or the flame from the fuse itself, may ignite gas at the face and start an explosion.

Safety device for fuse.

Recently a device has been placed on the market that is said to prevent the spitting of fuse, and hence the ignition of gas. This device consists of a tube that fits tightly over the outer end of the fuse and contains a composition that is ignited by turning a projecting wire. The device is successful in preventing the spitting of the fuse generally offered for sale in this country, but its value is greatly lessened by the fact that flame frequently bursts from the side of the fuse.

In some mines there is a tendency to economize by using short lengths of fuse. This is a bad and dangerous practice, for it is apt to result in a shot going off too soon.

Since electric detonators cost about as much as good fuse of the same length and are much safer, they should always be used in gaseous and dusty coal mines.

Misfires.

Fuse may cause misfires because of kinks or cuts, or because the gunpowder core is missing in places, or because the detonator, from not having been securely crimped, works loose from the fuse.

If the proper precautions are not taken, shots of permissible explosives may misfire. Such failures may be caused in one or more of the five following ways:

1. Imperfect detonation; generally the result of using a detonator that is too weak.
2. A displaced detonator.
3. The use of frozen or damaged explosive.
4. A short circuit caused by an imperfectly connected wire, or by the leading wire or the legs of the electric detonator having lost part of their insulation.
5. Defects in the battery or firing machine.

Prevention of misfires.

A statement of the causes of misfires indicates how misfires may be prevented. The detonators should be fresh and strong enough to explode the charge completely; they should be properly placed in the cartridge; the leading wires and the detonator legs should be properly insulated, and the battery should be in good condition. Leading wires and detonators should be carefully examined before each shot, and any bare places that are found should be properly covered. All frozen explosives should be thoroughly thawed before use.

At several mines in the eastern districts of the United States, the miners fire the shots of permissible explosives with fuse and detonator. The shots are generally fired either before the shift or in the early part of the shift. An examination of the results at the mines visited showed that this practice does not give as good results as having the firing done by special men, because of the miner's tendency to use more explosive than is needed to bring down the coal. This overcharging of shots increases the percentage of fine coal. Another disadvantage of such shot firing by miners is that the shots are not fired systematically. Still another and much more serious objection, particularly in gaseous mines, is the increased danger of gas being ignited, either in lighting the fuse or by the burning fuse itself. Many gas explosions have started from shots fired by miners. In addition, the dangers that attend handling all explosives are much increased by allowing miners to fire shots, because the explosives and detonators may be handled by men who are not familiar with the properties of the explosives or who disregard the risks in their use.

Shot firing by miners.

Danger of the practice.

The firing of permissible explosives in the chief coal-mining districts has been done by special men whose sole duty is to fire shots. The shot firer carries either a shot-firing lamp, a magneto machine, or a dry-cell battery with a safety-contact button. He goes from one working place to another loading and tamping the shots and, as soon as they are ready, firing them. No shot is supposed to be fired unless the working place is properly timbered and the shot firer is satisfied that the shot is properly placed. As the shots are fired in order, as far as is possible, the miner knows when to expect the shot firer and usually has his shots ready for loading and tamping as soon as the latter arrives.

Employment of shot firers.

Compared with the plan of allowing miners to fire shots, the employment of a shot firer leads to larger yields of lump coal, regulates better the quantity of explosive used, results in more systematic work, and maintains stricter discipline. Another advantage is that the plan prevents one miner loading out all his coal before his neighbor, and thus assures the driver having a uniform tonnage to haul during the entire shift.

Advantages of employing shot firers.

During recent years the mines that have the best discipline among those situated in districts where there is considerable gas, or where the roof is poor and much timbering is required, have been employing entry, district, or "face" bosses. These men are picked miners of much experience. Each entry boss patrols the working places in his charge to see that they are properly timbered and that the miner is always working under safe conditions. Some companies have found the services of these men of great value and there can be no doubt that the general employment of entry bosses

Shot firing by entry bosses.

would greatly lessen the number of accidents. If permissible explosives are employed and a mine is properly districted, these entry, district, or "face" bosses may also perform the duties of shot firer. The tamping and firing takes little time and since each boss has to visit each working place anyway, he can easily perform this small additional duty. Some mines in West Virginia and some in Pennsylvania have found this arrangement most satisfactory.

Ignitions of gas after shots.

It is extremely difficult to get correct information as to ignitions of gas after shots of permissible explosives. Shot firers and miners are apt to fail to report such ignitions, and when they refer to them later they do not recall the exact facts in each case. From what the writers have seen while following shot firers on their rounds, it seems extremely probable that by far the larger number of the ignitions laid to permissible explosives are really caused by bringing an open lamp to the face immediately after shooting, and holding it close to the face to see the results of the shot.

Diffusion of gases from shots.

If the coal is undercut and the holes properly charged, the shots do not scatter the coal, but merely drop it a few inches and open cracks and crevices at the roof and along the bedding planes; consequently the gases liberated from the coal and the gases from the explosive itself do not escape as freely as when, with excessive charges of black powder, the coal is blown away from the face and shattered. The inflammable gases from properly placed shots of permissible explosives diffuse slowly, and are easily ignited by an open flame held near the face immediately after shooting. The risk of ignition is just about the same as it would be if black blasting powder were used in smaller charges than are customary, and the coal were not blown from the bed but merely dropped on the floor. Some experiments made in a mine in northern West Virginia, in which open lights were used and little or no gas was found under ordinary conditions, showed the risk to be about equal with the two explosives. When open lights were brought to faces freshly blasted by permissible explosives and touched to cracks in the coal, gas was ignited in nearly every trial. When black powder was used and the coal was not scattered but merely dropped on the floor, the gas in the cracks of the face was ignited in just about the same proportion of trials.

Relative risk of igniting gas.

If the interval between firing a shot of a permissible explosive and bringing a naked flame to the face is at least five minutes, there should be little danger of the naked flame igniting gas.

EFFECT OF PERMISSIBLE EXPLOSIVES ON SIZE OF COAL.

Proportion of small coal made.

Permissible explosives have come into use so recently that it is not easy to get reliable figures showing the increased proportion of fine coal they make as compared with black blasting powder. The estimates of this increase given by mine superintendents run from no increase to 10 per cent. Some superintendents maintain that although smaller lumps of coal may be made by using permissible explosives, yet changing from black blasting powder to these explosives does not increase the proportion of fine coal. Some persons state that the lumps of coal produced by using permissible explosives are not so easily broken up during transportation or exposure to the air as are those made by using black blasting powder, whereas other persons maintain the reverse. However, if the coal is undercut or sheared and the blasting is done with judgment, the permissible explosives make as good coal as black blasting powder and at approximately the same cost.

Experience needed for best results.

When a mine makes the change from black powder to a permissible explosive, there may be a slight increase in the proportion of fine coal made; but a considerable part of this increase must be laid to the miners' lack of experience with the new explosive. Miners must become accustomed to the use of a new grade of black blasting powder before they can get good results with it, and each miner must learn by experience how best to shoot any coal bed that is new to him. In like manner, a miner must become accustomed to using permissible explosives, for these explosives are entirely different from black powder and must be used in a different way.

Need of several shots in thick beds.

From what the writers have seen in mines that use permissible explosives, they have come to believe that miners are apt to try to blast a thick coal bed with only one or two shots instead of using several shots, as they ought to. If such a bed were not undermined, either by a puncher or a chain machine, and the coal were being shot off the solid with black blasting powder, a miner would never think of trying to blast the bed in one bench, but would break the coal down by several shots, each shot depending for its success on the preceding one. The miner should use permissible explosives with equal judgment; if he does he will find that the proportion of lump coal produced compares very favorably with what he would get by the use of black powder.

COST OF MINING WITH PERMISSIBLE EXPLOSIVES.

Cost of black powder.

In a certain coal field, black blasting powder, which was said to cost the operator $0.95 or more per keg of 25 pounds, was sold to the miner at an agreed price of $1.75 per keg. In some coal mines, especially those in which coal is shot off the solid and large quantities of powder are used daily, the profit on the powder is considerable. Consequently, operators do not care to change from black blasting powder and lose the profit on it. A way of adjusting this difference when a change is made to permissible explosives is to find out the cost of powder for each ton of coal produced and to charge the permissible explosives to the miner at this rate, allowing for the difference in quantity needed to do the same work.

Cost of permissible explosives.

The price that the operator pays for the permissible explosives he furnishes the miner varies from 12 to 14 cents per pound. It is said that as a rule no profit has been made by the operator from selling these explosives, because the price charged the miner has been just enough to cover the wholesale price the operator paid and the expense of handling.

Cost of detonators.

The miner usually has to pay 0.5 cent per foot for fuse and 0.5 to 0.75 cent each for detonators. Where electric detonators are used it has been the practice for the operator to furnish them to the miner free. These detonators cost from 3 to 5 cents each, the price depending on the strength of the detonating composition and the length of the wires. One company that worked a coal bed about 7 feet thick and used electric detonators to fire the shots, reported that the cost of detonators was 3.5 cents for each shot. The cost for permissible explosives at the mine was 1.75 to 2 cents for each ton of run-of-mine coal produced. The daily output was 800 tons and the company paid each of the four shot firers it employed $2.75 per shift.

Relative cost of black powder and permissible explosives.

According to information received by Government officials from other districts where the cost of using permissible explosives has been carefully kept, there is little if any difference in the cost of blasting a ton of coal, whether permissible explosives or black powder are used. It is true that the comparison is based on different conditions; the figures for black powder were for mines where miners were loading and firing charges in a wasteful manner, whereas those for permissible explosives were from mines where shot firers were employed and the explosives were used in an intelligent way.

Records kept by another company show that the use of permissible explosives slightly increases the blasting cost per ton of coal produced, but the comparison with black blasting powder was made when the loading and firing of powder and of permissible explosives were done by shot firers.

In one mine that used nothing but black blasting powder and employed shot firers during the year 1909, the average cost of blasting, including the cost of squibs and the wages of the shot firers, was 3.15 cents for each ton of coal produced. The cost varied from 5.4 cents in March to 2.7 cents in August. The cost of shot firing averaged 1.1 cents per ton of coal. In the same district, in another mine, which used permissible explosives during 1909, the average cost of blasting, including the cost of electric detonators and the wages of the shot firers, was 3.3 cents per ton and the average cost of shot firing was 1.22 cents per ton.

Improper handling and care of permissible explosives.

Before permissible explosives leave the factory they are put in cartridges having a heavy paper wrapper that is made almost water and weather proof by a coating of paraffin or a similar substance. If the cartridges are carelessly handled, the paraffin coating may be broken; air and moisture can then act on the explosive so that it will lose strength and finally have no explosive power at all. Long exposure to the moist air of the mines or contact with water will also weaken and spoil the explosive, even though the paper cover is not broken.

MISUSE OF PERMISSIBLE EXPLOSIVES.

Excessive charges.

At the mines they visited the writers saw a number of instances of the misuse of permissible explosives. The most common form of misuse was the overloading of holes. This happened mostly at mines where miners fired their own shots and regular shot firers were not employed. A miner tries to bring down the coal completely without doing any more pick work than he has to, so he uses more explosive than is necessary. A shot firer, on the other hand, generally tries to get the maximum proportion of lump coal, and so uses only enough explosive to bring down the coal. For this reason a better quality of coal is had by employing shot firers than by allowing miners to charge and fire shots.

Hidden charges.

Another bad practice, said to exist at some mines using shot firers, is the insertion of small quantities of explosives in the back of holes before the arrival of the shot firer and without his knowledge. The miner may do this to hide the fact that the hole has been drilled into the solid and beyond the mining, or he may do it to insure the charge being large enough to satisfy him. However, the practice is most dangerous, and can not be condemned too strongly. At least one instance is on record of a miner putting dynamite into a drill hole that was to be charged with a permissible explosive. In this instance, as was to be expected, the shot gave a dangerously long flame, and an ignition and a fire resulted.

Igniting gas by a naked lamp.

The offense that miners commit most often is to bring a naked lamp in contact with the gases liberated or given off by the explosion of permissible explosives (see p. 23). Owing to the fact that these explosives when properly used make little or no smoke, the miner is tempted to return to the face immediately after a shot; and usually he does so, especially if he smells no offensive fumes. Then his naked lamp may ignite the gases from the explosive and those liberated from the coal. Tests in certain coal mines have shown (see p. 23) that it is possible to ignite the gases from a crevice in the face after a shot of either a permissible explosive or black blasting powder. Analyses of the crevice gases seem to prove that most of the inflammable gases found after shots come from the coal. A coal that contains much volatile matter may easily take fire from the ignition of crevice gas, and such face fires after they get a good start are very hard to put out.

ADVANTAGES OF PERMISSIBLE EXPLOSIVES.

Lessened risk of fire.

One of the most important advantages to be gained by using permissible explosives is the exemption from mine fires. If the explosives are properly employed, ignitions of gas or coal seldom happen.

"Fire runners" unnecessary.

In many mines working a high volatile coal that gives off considerable gas and produces large quantities of fine dust it has been necesary to employ, with every two shot firers, a miner or "fire runner" to follow and put out any fires caused by shots. This procedure was discontinued when permissible explosives were adopted. However, it is good practice to examine the face after a blast, no matter what explosive is used.

Less damage to roof.

Another important advantage is lessened damage to the roof. In blasting coal that has been undercut it is not necessary to give the drill holes as much lift for permissible explosives as for black powder. The holes for the latter, in order to shoot the coal to best advantage, must usually have considerable "lift"; as a result they are often driven into the roof coal or slate, which is so shattered by the blast that close timbering is necessary. But permissible explosives seem to throw down the coal well and to give a good proportion of lump coal if the holes are almost horizontal. Fired in such holes the permissible explosives appear to work out along the joints and the bedding planes of the coal instead of striking up into the roof or slate—provided, of course, that in placing the holes proper advantage was taken of slate bands or partings in the coal bed. Consequently if head coal is to be left for a roof, these explosives enable the miner to keep this roof smooth, firm, and unbroken, so that less timber is required to support it. In one mine that was leaving top coal in place, the change from black powder to permissible explosives did away with the need of employing a regular timberman.

Cleaner ribs.

Charges of permissible explosives can be and generally should be placed 1 or 2 feet from the ribs and will still bring down the coal. In some coal fields the ribs are cut much cleaner by such shots of permissible explosives than they can be cut by shots of black powder. In one mine the replacing of black powder by a permissible explosive increased the yield for each cut $1\frac{1}{2}$ tons because of the trimming effect of the permissible explosive.

Fewer blown-out shots.

On the other hand, if a hole for a permissible explosive is drilled too deep on the solid, the explosive uses up its strength in making a cavity at the back of the hole without breaking down the solid coal. If charges of black blasting powder are fired in such deep holes, blown-out shots often result, but with permissible explosives blown-out shots are rare and are not accompanied by flame.

Less scattering of coal.

If rightly used, permissible explosives do not scatter the coal over the gob, where it is lost, nor do they displace props, as frequently results from the use of black powder. When coal properly undermined is blasted with permissible explosives, it is not thrown out nor much displaced, but is merely dropped in its bed, although it is generally broken up enough to be easily loaded.

Fewer air blasts and windy shots.

Another advantage of permissible explosives, when properly used, is that the shots do not give as heavy shocks to the mine air as do shots of black blasting powder. Consequently, brattice, doors, and stoppings are not subjected to air blasts as strong as those often felt when black powder is used. Still another advantage is that it becomes easy to get men to act as shot firers, because there are no windy shots and little danger of dust explosions.

The permissible explosives are cleaner and much more convenient to use and handle than black powder; moreover, they can be prepared and fired much more quickly. If rightly used, they do not scatter coal nor dislodge timbers, and thus they make the working places safer; moreover, they greatly reduce the danger of starting explosions. Permissible explosives also save time, because they do not make smoke and the miner can more readily examine the roof after a blast.

A charge of a permissible explosive takes up only about one-half the space that a charge of black blasting powder heavy enough to do the same work would occupy; hence for the same depth of hole much more stemming can be used with a permissible explosive than with the black blasting powder and there is a reduction to a minimum of tendency to blow out stemming. This is another reason why the use of permissible explosives tends to do away with blown-out shots, and thus greatly increases the safety of every person in a coal mine.

Used in wet holes.

Still another advantage connected with the use of some permissible explosives is the ease with which they can be used in wet or damp holes. In shooting off the solid in thick coal beds some bottom holes may be so wet that they can not be fired with black powder. In one mine that was visited, permissible explosives were successfully used to shoot such wet bottom holes.

Necessary in gaseous mines.

In blasting coals that contain much volatile matter or gas the use of permissible explosives is absolutely necessary. In such mines black powder or dynamite may ignite bodies of fire damp in the advance working places or strong feeders of gas at the face. Permissible explosives give such short, quick flames that if the coal is undercut and the holes are properly placed and charged, the chance of igniting gas is reduced to a minimum.

Results of use in Oklahoma and southern Illinois.

In two important and widely separated coal-mining districts, southern Illinois and Oklahoma, permissible explosives are used to some extent in driving entries in beds that give off considerable gas and in which the coal is so brittle that it makes much fine dust. The permissible explosives are used in the entries and in some mines in the rooms as well. Before the permissible explosives were tried, the coal was set on fire nearly every day through the ignition of gas feeders, but since the permissible explosives have been used no such fires have been reported.

Use for blasting off the solid.

Permissible explosives are used in several districts to blast coal off the solid. Such use is reported to be successful in certain mines in Alabama, but as a rule does not give nearly as good results as when the coal has been undermined. The coal is usually more broken up than it would be if undercut before shooting, and the necessarily larger charges of explosives tend to weaken the roof and to increase the danger of roof falls.

Absence of smoke.

One of the most important advantages of the use of permissible explosives, if properly fired in suitably prepared drill holes, is the absence of smoke. If just enough of the permissible explosive is used, little, if any, smoke is produced. This feature is especially important in mines where the roof is bad. The ventilating current is not fouled by large quantities of dense smoke, as is the case when black powder is employed, and slips or cracks in the roof can be more easily and quickly seen. However, the charge must be properly fired; otherwise noxious gases may be given off and these may have disagreeable or even dangerous effects upon the miner.

Fumes from permissible explosives.

Miners frequently complain of the fumes given off from shots of permissible explosives, but in the many mines using these explosives that were visited by the writers of this bulletin fumes seemed to give little or no trouble. In none of the places examined did the fumes from blasts cause discomfort. If the ventilating current is brought directly up to the working face, no discomfort should be caused by shots of permissible explosives, if these explosives are properly used. This advantage, however, leads to a risk in their use, since the miner is tempted to go back to the face as soon as a shot is fired. This is a very dangerous thing to do, no matter what kind of an explosive is used, and should be strictly forbidden.

Quantity of poisonous gases.

If the coal is properly undercut or sheared and a charge of 1½ pounds to a hole has not been exceeded, the quantity of poisonous gases produced by the permissible explosive itself is so small that it is of little, if any, consequence. It is easy to understand why the gases should not be troublesome if one remembers that the volume of gases produced by firing 1½ pounds of an explosive is soon diluted by several thousand cubic feet of air.

Fumes from black powder.

Black blasting powder containing Chile saltpeter, and permissible explosives of each of the four classes that have been mentioned (p. 9) were tested by firing shots in coal mines. Electric detonators strong enough to cause complete detonation were used. The charges of permissible explosives varied from 13 to 24 ounces. Samples of air were taken near the face before each shot, and at the same place at intervals of 20 seconds, 2 minutes, and 4 minutes after the shot. To ascertain the quantity of harmful gases that remained in badly ventilated places the experiments were tried in working places ahead of the air, generally in blind entries. None of the samples of the mine air taken immediately after the blasts of the different explosives was found to contain more than a trace of any poisonous gas.

Gases remaining in mine air.

Gases from crevices.

However, although the samples of air collected immediately after blasts of the different explosives did not contain measurable quantities of poisonous gas, yet in all the mine tests of explosives, samples of the gases taken immediately after blasting from the crevices made in the coal by the shot contained large quantities of poisonous or inflammable gas. Because these gases escape from the face slowly, a miner should never return at once to the face after a blast, but should always wait at least five minutes. It is known that the gases continue to come from the crevices for several minutes after a shot. They mix with and are diluted by the air of the working place. Analyses of crevice samples also show that in non-gaseous bituminous coal mines 8 to 27 per cent of inflammable gas, largely methane (CH_4), is formed with each shot of an explosive; this gas is believed to come from the pores of the coal, whence it is forced or drawn by the explosion of the charge.

Proportion of carbon monoxide in such gases.

Analyses of samples of air collected after shots in mines also show that more of that poisonous gas, carbon monoxide, or white damp, is formed in blasting coal than is formed by exploding equal charges of the same explosives in the pressure gage used to test explosives at the Pittsburgh station. Part of the extra carbon monoxide is believed to come from the ignition by the explosive of fine coal left in the drill hole and part from the coal itself. Explosives that produced no carbon monoxide when exploded in the pressure gage always produced some carbon monoxide in the tests in coal mines, and those that yielded a relatively high percentage of carbon monoxide in the tests in the pressure gage gave a correspondingly large yield in the mine tests.

Gases from black blasting powder.

A typical analysis of the gases collected from a crevice at the face 20 seconds after a shot of black blasting powder containing Chile saltpeter is given below; allowance is made for the air mixed with the gases and for the same percentage of methane that was in the gases resulting from the explosion of the powder in the pressure gage.

Gases from a shot of black blasting powder.

	Per cent.
Carbon dioxide (CO_2)	19.2
Carbon monoxide (CO)	28.1
Oxygen (O_2)	.0
Hydrogen (H_2)	10.0
Methane (CH_4)	.6
Hydrogen sulphide ((H_2S)	6.8
Nitrogen (N_2)	35.3

The analysis shows that the poisonous gases (carbon monoxide and hydrogen sulphide) generated by this black blasting powder form 34.9 per cent of the whole volume of the gases produced.

Gases from permissible explosives.

A typical analysis of the gases, taken under the conditions above referred to, from a permissible explosive that gave in mine tests the largest proportion of poisonous gases, is as follows:

Gases from a shot of a permissible explosive.

	Per cent.
Carbon dioxide (CO_2)	26.7
Carbon monoxide (CO)	36.4
Oxygen (O_2)	.0
Hydrogen (H_2)	14.2
Methane (CH_4)	1.4
Hydrogen sulphide (H_2S)	.0
Nitrogen (N_2)	21.3

A typical analysis of the gaseous products of a permissible explosive that gave the smallest proportion of harmful gases in the field tests and did not give any carbon monoxide in the gage tests is as follows:

Gases from a shot of a permissible explosive.

	Per cent.
Carbon dioxide (CO_2)	18.0
Carbon monoxide (CO)	6.4
Oxygen (O_2)	.0
Hydrogen (H_2)	8.2
Methane (CH_4)	.5
Hydrogen sulphide (H_2S)	.0
Nitrogen (N_2)	66.9

Many samples of gas were taken from crevices made in the coal by shots of different explosives, and these samples were analyzed. The analyses show (after allowance is made for the air in the sample and for the proportion of methane found by tests in the pressure gage) that the gas from crevices after blasts with various permissible explosives contained, on an average, 19.5 per cent of carbon monoxide.

Gases from shots are poisonous and inflammable.

The results of these mine experiments indicate that the gases from the explosion of any of the explosives tested are mixed with the gases that come from the coal itself and that the mixtures formed are extremely poisonous and inflammable. Since these gas mixtures are inflammable, it is easy for a miner to ignite them by holding an open flame to a crevice just after a shot. To ignite crevice gas in this way, however, is a most dangerous practice and should be strictly forbidden.

The experiments in mines showed also that four minutes after a shot the greater part of the crevice gases had passed into the mine air and were so diluted that measurable quantities of them could not be found in the samples of mine air collected.

All of the mine tests just mentioned were made in the Pittsburgh district. The coal had been properly undercut and only enough explosive to do the work was used for each shot. If the charges of permissible explosives are heavier than they need be, it is reasonable to suppose that harmful gases in quantities sufficient to be injurious to the health of the men employed may be given off. The remedy, of course, is not to stop using permissible explosives, but to use smaller charges.

Permissible explosives make mining pleasanter and safer.

The facts gathered by the writers make it clear that if all coal mines in this country would stop using black blasting powder and would use permissible explosives instead, the miners would find their work pleasanter and safer. Of course, the explosives would have to be used properly and would have to be fired so that their detonation would be complete. In other words, the coal would have to be undercut and the shots charged and fired by shot firers who use electric detonators. Unless they are properly used permissible explosives will not give the best results and may yield dangerous quantities of noxious or inflammable gases.

EXAMPLES OF GOOD PRACTICE IN THE USE OF PERMISSIBLE EXPLOSIVES.

The writers, in their examination of mines that use permissible explosives, noted various features of practice. Some features that seemed particularly good will be described here.

Driving headings.

In one large mine the headings were driven 10 feet wide and the rooms 20 feet wide, leaving room pillars 40 feet thick. The coal was strong; the bed was about 8 feet thick and had a fairly good shale roof. In most places 8 to 12 inches of top or head coal was left to support this roof.

The coal in headings and rooms was undermined by chain breast machines. The rooms were six runs wide and the headings were three

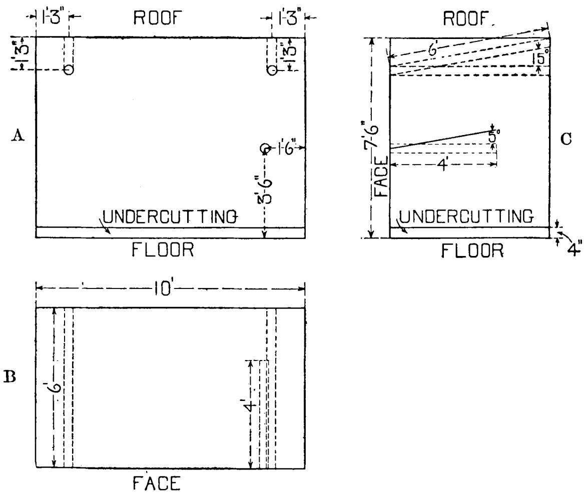


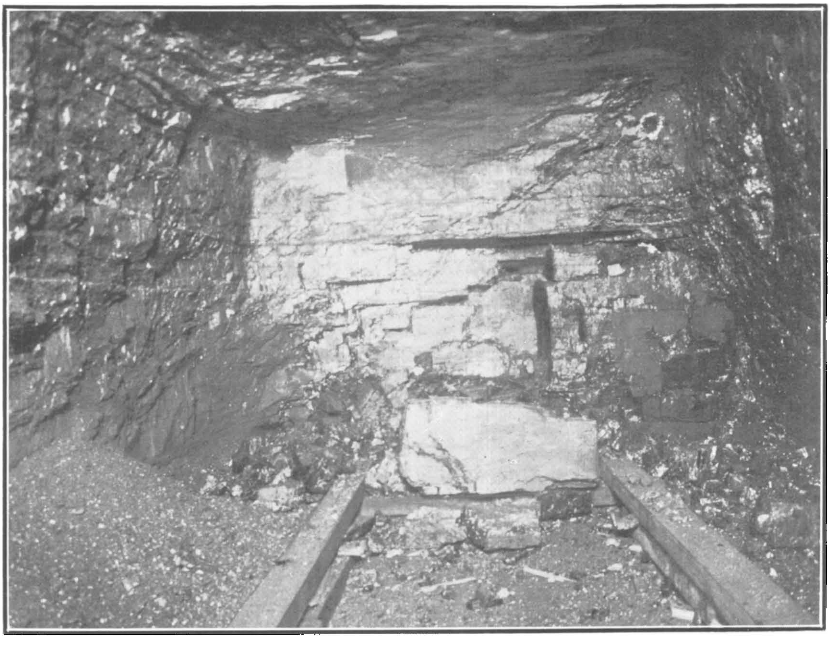
FIGURE 1.—A proper arrangement of holes in a heading with coal undercut. A, front view; B, plan; C, side view.

runs wide. The undercut was about 4 inches high and 6 to 7 feet deep.

In most places the headings were shot by three holes, charged with a permissible explosive of the ammonium-nitrate class. The holes were placed in the following manner:

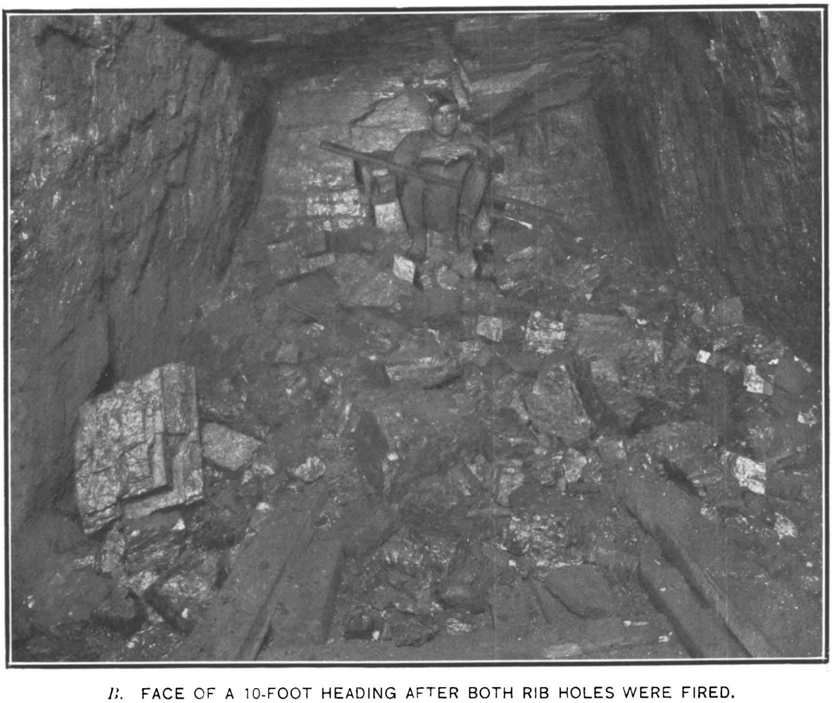
A "block" hole 3 to 4½ feet deep was started about 3 feet from the floor and driven parallel to and but a few inches from the right rib. It was usually pointed downward at an angle of 3° to 5° with the horizontal.

A. FACE OF A 10-FOOT HEADING WITH THE "BLOCK" HOLE AND THE RIGHT RIB HOLE DRILLED.



B. FACE OF A 10-FOOT HEADING AFTER THE "BLOCK" HOLE WAS FIRED.

A. FACE OF A 10-FOOT HEADING BEFORE FIRING OF RIB HOLES. COAL FROM "BLOCK" HOLE LOADED OUT.



B. FACE OF A 10-FOOT HEADING AFTER BOTH RIB HOLES WERE FIRED.

Two rib holes were driven; one was 6 feet in depth and a few inches from and parallel to the right rib; the other was 6 feet in depth and a few inches from and parallel to the left rib. These two holes were placed like the right rib hole shown in Plate I, *A;* they were started 6 to 18 inches from the upper corner and were pointed upward at an angle of 10° to 15° with the horizontal. Plate I, *A*, shows a view of the face of a heading 10 feet wide with the "block" hole and the right rib hole drilled.

The "block" hole was fired first and, as a rule, yielded a much smaller quantity of lump coal than the other holes. (See Pl. I, *B*.) The usual charge was one and one-half to two sticks (0.75 to 1 pound) of the permissible explosive. When the coal from the "block" shot was loaded out (see Pl. II, *A*), the rib shot over it was fired. An ordinary charge for the rib holes was from one and one-half to two and

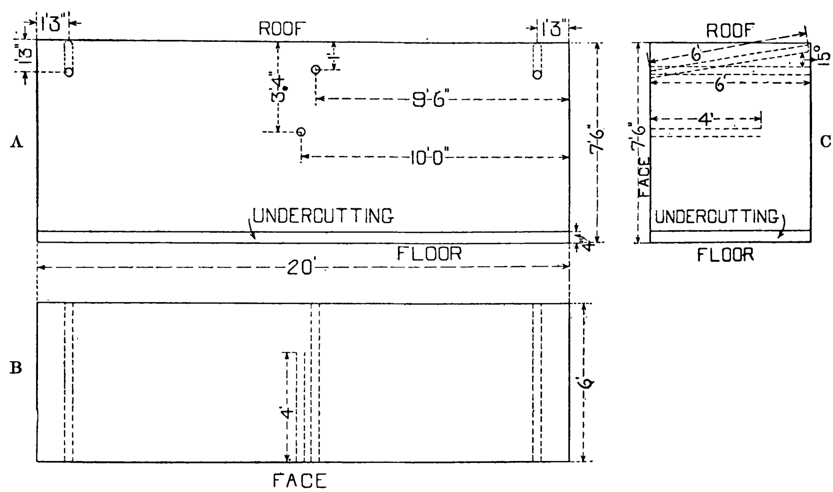


FIGURE 2.—A proper arrangement of holes in room with coal undercut. A, front view; B, plan; C, side view.

one-half sticks. Immediately after this shot and before the coal from the first rib shot was loaded out the other rib shot was fired. Plate II, *B*, shows the results of firing the rib shots. Figure 1 shows the arrangement of shot holes in headings.

Driving rooms.

The rooms were 20 feet wide and were usually widened out on one side; the coal was undercut to a depth of 6 feet. Four holes (Pl. III, *A*, and fig. 2) were used to shoot the rooms: one "block" hole, one "breaker," and two rib holes. Plate III, *A*, shows the coal face and arrangement of drill holes and figure 2 shows the lengths and angles of the holes.

The block hole was drilled to a depth of 3 to 4 feet either horizontally or pointing downward at an angle of 3° to 5°. This hole was started at about the center of the room and 4 to 4½ feet above the floor; it was driven parallel to the ribs. The charge, two to three sticks of explosive, was fired after just enough of the "bugdust" made by the mining machine had been loaded out to clear the shot.

The breaker hole was 6 feet in depth. It usually started about 2 feet above the block hole and 8 to 10 inches from the roof, extended upward at an angle of 10° to 15°, but parallel to the ribs, and ended at the roof coal, 8 to 10 inches of which was left in place. The breaker shot was not fired until the coal yielded by the block shot had been entirely loaded out. Generally one and one-half to two and one-half sticks sufficed for the breaker shot, and as the coal was left free by the removal of coal brought down by the block shot the coal yielded by the breaker was of good quality. Plate III, *B*, shows the face after the coal from the block shot had been loaded out and previous to firing the breaker shot. Plate IV, *A*, shows the shot firer and the miner charging the breaker shot.

Sometimes a little shearing was done by the miner just after the coal from the breaker shot had been loaded out and previous to firing the rib shots. This shearing freed the rib shots which, charged with two to two and one-half sticks each, were fired one immediately after the other. These shots usually yielded the best coal from the face, as they were entirely free. Plate IV, *B*, shows the face before the rib shots were fired, and Plate V, *A*, shows the face after firing.

If the block and breaker shots were not exactly in the center of the room or not parallel to the ribs, one of the rib shots was usually smaller than the other. The firing was done entirely by shot firers who patrolled the working places and fired the shots, at the request of the miner, by means of magneto firing machines. No shot was fired until the working place was properly timbered, and no holes were fired that were driven any distance on the solid. A coil of double No. 18 leading wire 75 to 100 leet long was used to carry the electric current from the battery to the face. Electric detonators with 8-foot legs were used to detonate the charge. They cost 4 cents each. One shot firer was employed for approximately each 300 tons of daily output. The miners worked singly in rooms and headings. The company hired the shot firers and furnished the electric detonators. The miners furnished the explosives, which cost them 14 cents per pound. The shot firer generally tamped and fired each shot in three to four minutes' time.

Stemming.

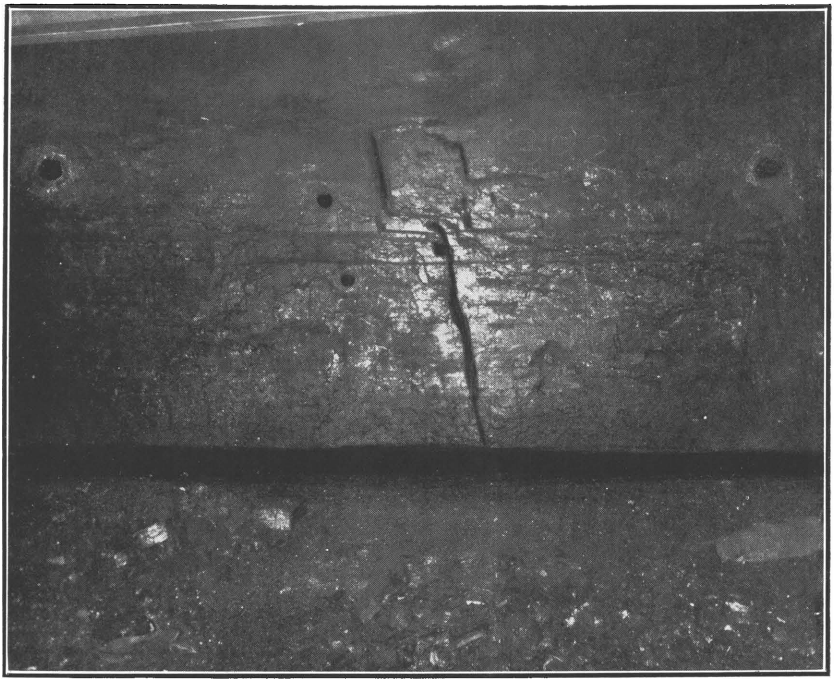
In the mine cited on page 26, moist yellow clay was used for stemming. This clay was obtained outside the mine, brought into the workings on mine cars, and placed at convenient points along the headings. Another mine using permissible explosives employed the fire clay taken from the floor in the mine. In both mines the clay was formed into "dummies," or clay cartridges, by wrapping paper around a cartridge stick and filling the

A. SHOT FIRER AND MINER CHARGING "BREAKER" HOLE IN ROOM.

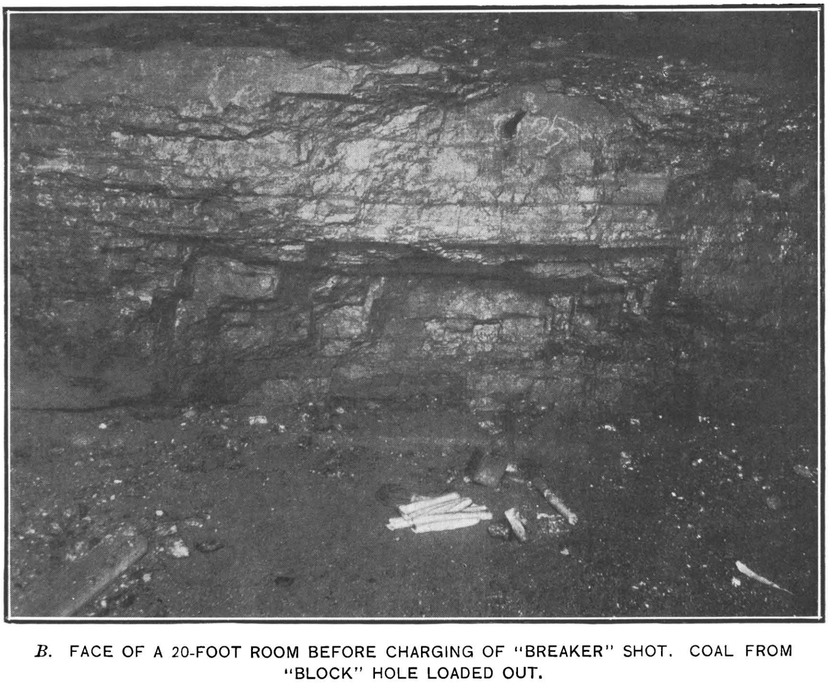
B. FACE OF ROOM BEFORE RIB HOLES WERE FIRED. COAL FROM "BREAKER" HOLE LOADED OUT.

A. FACE IN 20-FOOT ROOM AFTER FIRING OF BOTH RIB SHOTS.

B. MODEL, NEAR MINE MOUTH, OF THE ARRANGEMENT OF SHOT-FIRING WIRES IN A MINE.



A. COAL FACE AND ARRANGEMENT OF DRILL HOLES IN A 20-FOOT ROOM, ONE "BLOCK" HOLE, ONE "BREAKER," AND TWO RIB HOLES.



B. FACE OF A 20-FOOT ROOM BEFORE CHARGING OF "BREAKER" SHOT. COAL FROM "BLOCK" HOLE LOADED OUT.

case with moist clay. These dummy cartridges were 10 to 12 inches in length and about 1½ inches in diameter. It was customary for the miner to have the explosive and "dummies" ready at the working face when the shot firer made his round of the places.

A round wooden stick, 1½ inches in diameter and 7 feet in length, was used to tamp the powder and stemming.

Size and position of drill holes.

The drill holes varied in diameter from 1¾ to 2¼ inches. They were drilled to the depth of the mining and no farther. The block and rib holes were driven horizontally whenever they could be, because the shots in the flat holes "cut out" horizontally, yielded better lump coal, and did not "cut up" into the roof coal as much as did those in inclined holes.

ELECTRIC FIRING OF SHOTS.

As a result of efforts to make the firing of shots in coal mines safer, systems of firing by electricity have been developed. These systems, in the best practice, require that all men shall be out of the mine before any shots are fired. The essential features of a good electrical firing system are as follows:

Arrangement of wires.

The mine is wired with rubber-covered wires laid in parallel in order that one defective shot may not prevent others from being fired. On the main entries No. 6 rubber-covered wire is used, on the cross entries No. 10 or No. 12, and in the rooms No. 14 wire. These wires are hung from props or from plugs set in the roof. At the mouth of each cross entry there is placed a locked box in which there is a single-pole double-throw switch that is arranged to open downward to avoid accidental contact by falling. A similar, though smaller, switch is in some mines placed at the mouth of each room, or else the room wire is connected to the wire on the cross entry without the use of a switch. At the mouth of the mine there is a shot-firing cabin in which a 100-ampere, two-pole, single-throw switch is placed. There is a similar switch of the same size in the power house. This plan insures that there shall always be at least three open switches between the mine and the power house when the shot is being connected up.

Figure 3 illustrates the arrangement of shot-firing wires in a mine room. Plate V, *B*, shows a model of the same wiring placed outside the mine.

Operation of system.

The operation of the system is as follows: Every employee in the mine is given a brass check with his number stamped upon it. Upon entering the mine he hangs his check upon a check board in the shot-firing cabin. This board has painted upon it numbers which correspond to the numbers on the checks, and each check is hung over the proper number. No one is allowed to

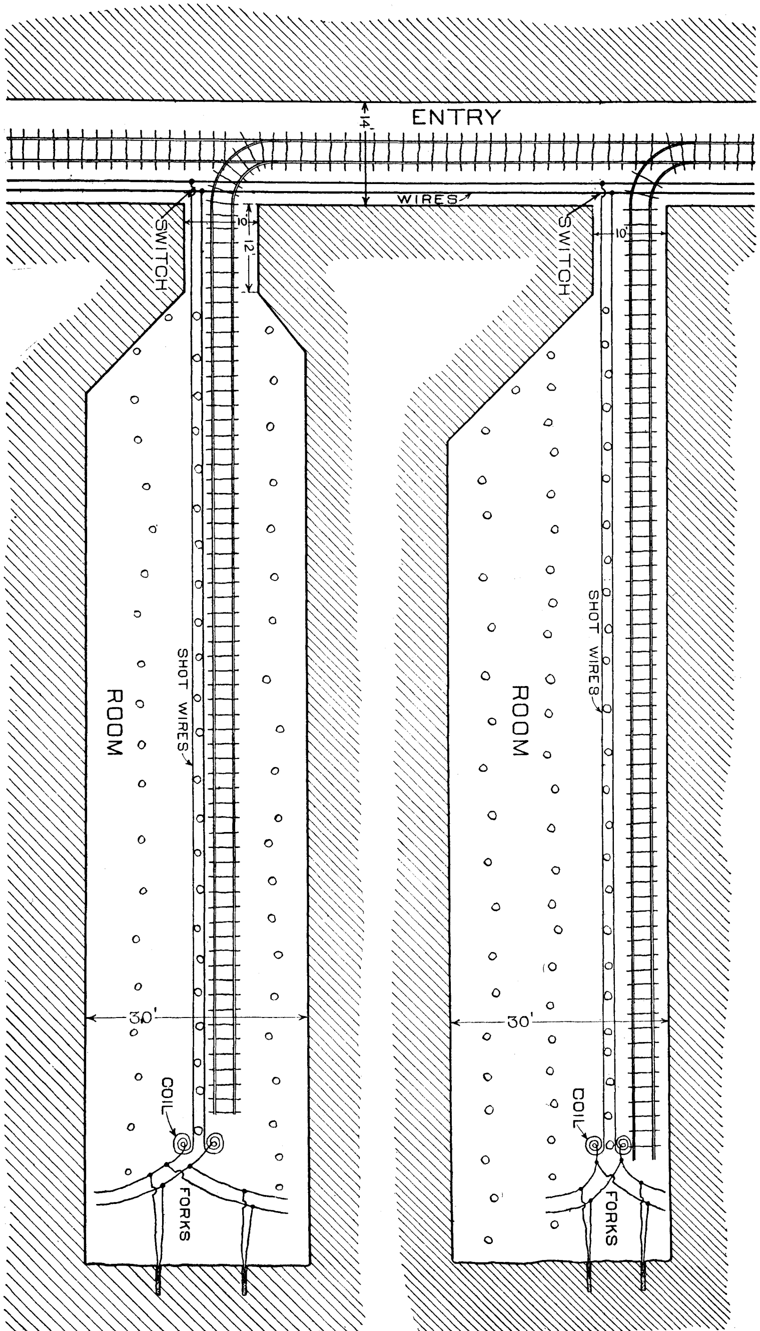


FIGURE 3.—A proper arrangement of shot-firing wires in a mine room.

enter the mine unless he has previouslv hung up his check on the check board.

Usually the miners are allowed a certain maximum number of shots for each working place—generally three. The coal is undercut in most places, and permissible explosives are used. Special shot firers go through the mine during the day examining the shots as they are being prepared by the miner and distributing the electric detonators. In some instances the miner tamps the shots himself; in others the shots are tamped by the special shot firers. If the miner tamps the shots, he connects the detonator legs sticking out of the shot hole to the No. 14 wire, which extends up the roadway of the room, notes that the connection at the room mouth is made, and then leaves the mine. In connecting the detonator legs to the No. 14 wire care is taken to strip the insulation off the lead wires and to wrap the legs around the No. 14 wire, not looping them, as is done in some mines.

After all the miners have left the mine the shot firer goes through each entry and notes that the switch at the mouth of each room is closed or that the connection is made at the room mouth if the switch is not used. At the mouth of each cross entry he unlocks the switch box, throws in the switch, and locks the box. He then proceeds to the mouth of the mine, enters the shot-firing cabin, and notes that all the checks have been taken off the board, which signifies that the check owners have left the mine. If any checks are still remaining on the board, he searches the mine until the men represented by the checks are found, or if any miner has left the mine without taking his check with him this fact is determined. Usually there is a fine provided for failure to leave or take away a check at the proper time.

When the shot firer has ascertained that all the checks have been taken from the board, he then goes to the power house, where there is a switch provided, and generally an electric generator giving direct current of about 500 volts, to fire the shots. The shot firer instructs the man in the power house to throw in the power-house switch and then returns to his own cabin, unlocks the switch box there, and throws in the switch, thus firing all the shots in the mine. After the shots have been fired, the shot firer opens the switch and locks the box.

There are always some misfires, caused by carelessness in making connections, by falls of roof deranging the wires, or by projecting portions of the roof cutting the insulation off the wires. The fire boss goes into the mine about an hour after the shots have been fired and unlocks each box, throws out the switch, and locks the box again. He then proceeds to each working place, notes what shots failed to go off, and connects them up properly. When he leaves the mine at the close of his shift he unlocks each box, throws in the switches, and fires the shots just as a shot firer on a day shift would do. By this procedure the number of failures is reduced to a minimum. The average proportion of failures is said to be about one-half of 1 per cent, or about one failure to every 200 shots.

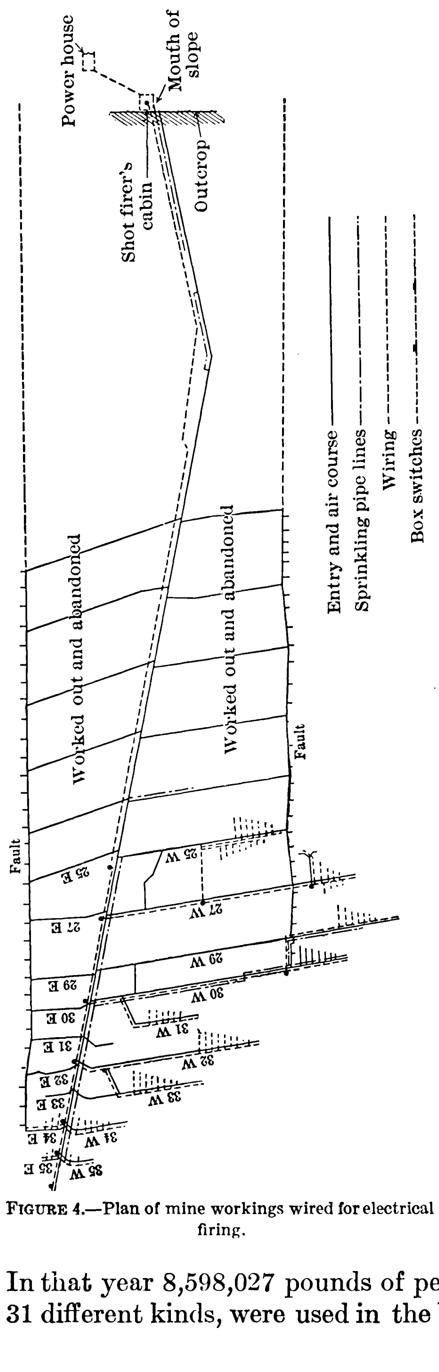


Figure 4.—Plan of mine workings wired for electrical firing.

Figure 4 shows a plan of mine workings wired for such a method of electrical firing.

The cost of equipping a mine for firing shots by the method above outlined varies from $1,000 to $3,000, depending upon the size of the mine. The maintenance and operation of the system is said to cost from 1 to 3 cents per ton. It has been used successfully for some time past in some coal fields, and its adoption in other fields, where permitted by local conditions, would reduce accidents in coal mines.

SUMMARY.

The successful methods that have resulted from the efforts made in European coal-producing countries to reduce explosions in coal mines are rapidly being put in operation in the United States.

Factors that are making mining safer.

Following the example of Great Britain, Belgium, and Germany, a large number of the coal-mining States of this country are restricting the use of black blasting powder in the more dangerous coal mines. In consequence, permissible explosives are rapidly taking its place. The table on page 9 clearly shows the marked increase in the use of safer explosives during 1909. In that year 8,598,027 pounds of permissible explosives, representing 31 different kinds, were used in the United States. In the mines and quarries of Great Britain there were used, in the same year, 8,502,232 pounds of "permitted" explosive, representing 48 different kinds.

Better regulations for the storage and handling of explosives for use in coal mines are being adopted by many of the large mining companies.

The quantity of explosive to be taken into a mine is limited, in many districts, through the action of State authorities and the more progressive operators.

Special men known as shot firers are employed in many mines for loading, tamping, and firing all explosives. Some mines have adopted the excellent practice of giving these men charge of the handling of explosives.

The system of firing shots from the surface by electricity after all men are out of the mine, first adopted in Utah, is being introduced in Colorado, New Mexico, Alabama, and other States.

Coal dust or other combustible and therefore dangerous material for stemming is being replaced at mines in all parts of the country by clay or other incombustible material.

The practice of wetting the coal dust in the mines, by watering the sides and roofs of working places and by humidifying the mine air with steam jets or water sprays has spread rapidly in the past two years.

State mine inspectors enforce mining laws and the regulations governing coal mines much better now than they did a few years ago.

The measures taken in this country to prevent explosions in coal mines are becoming nearly as effective as those adopted in Europe, and the proportion of deaths caused by explosions will grow smaller as preventive measures become still more effective.

PUBLICATIONS ON MINE ACCIDENTS AND TESTS OF EXPLOSIVES.

The following Bureau of Mines publications may be obtained free by applying to the Director, Bureau of Mines, Washington, D. C.:

BULLETIN 15. Investigations of explosives used in coal mines, by Clarence Hall, W. O. Snelling, and S. P. Howell, with a chapter on the natural gas used at Pittsburgh, by G. A. Burrell, and an introduction by C. E. Munroe. 1911. 197 pp., 7 pls.

BULLETIN 17. A primer on explosives for coal miners, by Charles E. Munroe and Clarence Hall. 1911. 61 pp. 10 pls. Reprint of United States Geological Survey Bulletin 423.

BULLETIN 20. The explosibility of coal dust, by George S. Rice, with chapters by J. C. W. Frazer, Axel Larsen, Frank Haas, and Carl Scholz. 1911. 205 pp. 14 pls. Reprint of United States Geological Survey Bulletin 425.

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