METHODS OF PREVENTING AND LIMITING EXPLOSIONS IN COAL MINES

BY

GEORGE S. RICE AND L. M. JONES

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METHODS OF PREVENTING AND LIMITING EXPLOSIONS IN COAL MINES.

By George S. Rice and L. M. Jones.

INTRODUCTION.

Although advance in the knowledge of mine explosions, particularly coal-dust explosions, has been slow, yet since investigations were begun in 1908 by the testing stations of various countries, progress has been steady, each station contributing to the general fund of knowledge.

During the fiscal year ended June 30, 1914, the Bureau of Mines had an especially fruitful period of investigation, available funds being sufficient to carry on an important series of large-scale explosion tests at the experimental mine at Bruceton, Pa., in order to determine the relative explosibility of different mine dusts and the efficiency of various methods of preventing and of stopping explosions. The large-scale testing for relative inflammability was supplemented by inflammability tests in the laboratory. In all, the explosion experiments were undoubtedly the most important and instructive of their kind ever conducted in this country.

During the year the work was greatly stimulated by a month’s visit of J. Taffanel, the distinguished director of the French testing station at Liévin, who collaborated with the bureau’s representatives at the experimental mine in making standardizing tests that would permit the comparison of the more important results with those obtained in the French testing gallery, and also with the results of the small group of experiments made in the Commentry mine, France. The tests were designed more particularly to determine (1) whether the same percentages of ash and other inert matter in the dust mixtures for a similar class of coal would prevent ignition of the dust from a blown-out shot, and (2) whether a strong explosion of gas or dust would be propagated throughout a long adjacent zone containing such mixed dust.

While Taffanel was present certain barrier devices that had proved effectual in the French gallery were tested to ascertain whether they would prove effectual under American mine conditions, and also to compare their efficiency with barrier devices devised by the bureau.
Although the French devices proved effective, the bureau's seemed better suited to the usual American mine conditions.

Much information was obtained from the tests conducted during the year in determining the velocity of propagation of explosions, the pressure obtained at certain stages with different mixtures, and the gases produced. At the time of preparing this publication the data are being compiled, but compilation and correlation of the large mass of data will take considerable time. Therefore, it has been considered expedient to publish promptly a brief report of such practical results as may be applied to the prevention and stopping of explosions. Especially it is hoped that the suggestions may lead operators of dusty bituminous mines to take additional safeguards during the winter and early spring, because it has been demonstrated that there is especial danger of coal-dust explosions during and following cold weather, owing to the natural drying out of coal dust in the mines. Of course, it must be fully understood that precautions must not be neglected at any time in the year; the issuance of methane into the mines is not affected by seasonal changes, and in extensive mines, if watering of some sort is not practiced, dry dust is frequently found in abundance in the interior of the mine, even in warm, humid weather. The final proof of a safe condition where watering or humidifying is employed is to have the dust wet in every part of the mine, and at all times of the year.

ACKNOWLEDGMENTS.

The authors take this occasion to acknowledge the inspiring support of Director Holmes and the efficient work of their associates in these investigations, particularly that of J. K. Clement, physicist, and W. L. Egy, assistant physicist. The task of keeping the experimental mine in good order and in preparing for tests largely devolved upon H. C. Howarth, mine foreman, who performed this work in a most creditable manner.

CAUSES AND PREVENTION OF EXPLOSIONS IN MINES.

Investigations of mine explosions have demonstrated that widespread explosions are preventable if methods that have been tested in an experimental way and in practice are used, and if care is taken at all times by everyone in the mine. In other words, explosions can no longer be considered "acts of God" for which no one is responsible.

No better illustration of the advantage of carefulness can be found than in the mines of Belgium. In those mines great instantaneous outbursts of inflammable gas from the measures into the mine workings are frequent, sometimes smothering the men, yet for the past 20 years no explosions of any magnitude have occurred through
ignition of the gas, though prior to 1893, when less precautions were taken, there had been many great disasters.

The adoption of preventive means or devices is largely in the hands of mine operators, but in the carrying out of the provisions every mine employee is concerned, particularly in a gaseous mine, or in a mine where inflammable gas is sometimes encountered.

It has been usual to discuss the methods of preventing fire-damp explosions as entirely apart from the methods of preventing coal-dust explosions; but in many of the most important coal-mining districts of the United States the sources of danger are much the same.

In general it may said that explosions may be prevented (a) by an absence of source of ignition, or (b) by an absence of inflammable or explosive matter like coal dust or fire-damp.

**SOURCES OF IGNITION.**

Sources of ignition are open flames of any sort, such as matches, open lights (in distinction to safety lamps, or permissible electric lights), flames from black powder, dynamite, or other nonpermissible explosive; electric arcs from grounding of trolley or power wires, and flames from mine fires. These sources of ignition have been described in other publications of the bureau, and will not be discussed here; the control of the agencies mentioned is of the utmost importance in the prevention of explosions.

Without open flame of some sort there would be no explosions. Permissible explosives produce some flame, but their flame is so small and its duration so brief that if properly used they will not ignite gas or dust; and if they were employed throughout the coal mines of the country to the exclusion of black powder, dynamite, and other explosives of a character dangerous to use in coal mining it is believed by bureau engineers that nearly one-half of the explosions would be prevented.

If safety lamps or permissible electric lamps were used, even in so-called nongaseous mines, it is thought that over one-third of all the explosions in this country would be prevented. Unfortunately the statistics of mine explosions for the United States as a whole do not clearly or accurately define the character of each explosion, nor its cause. Statistics are furnished to the Bureau of Mines by the State inspection departments, but a variety of methods is employed by the different States in gathering and grouping the statistics. Some States classify explosions according to the means by which they are propagated, such as coal dust, regardless of whether fire damp has first been ignited, whereas others name the source of ignition, as for example "a blown-out shot" or "a windy shot." So far as explosions are concerned, the best plan seems to be to classify by the means
of propagation regardless of the source of ignition, and separately to
give the primary cause, such as "open light igniting fire damp," or
"explosive igniting coal dust."

FIRE DAMP AS A SOURCE OF EXPLOSIONS.

It is observed by the field engineers of the bureau that the unexpected
presence of fire damp is a most important factor in the starting of
mine explosions. In many a so-called nongaseous mine, gas issues
in small feeders at the face in some part of the mine, as a matter of
daily occurrence; yet open lights are used in such a mine. This is
particularly a source of danger in those Alabama and Oklahoma
mines in which much fire damp is found. Also there are many mines—
doubtless over one-half of the coal mines of the United States—in
which feeders are occasionally reported, and sometimes the fire boss
in his morning rounds finds small bodies of standing gas; yet mines
with these conditions are also rated as nongaseous, and open lights
are freely used, despite the fact that a considerable proportion of the
explosions have occurred in just such mines through the ignition of
a pocket of gas by long-flame explosives or by an open light.

EXPLOSIONS MOST FREQUENT IN SO-CALLED NONGASEOUS
MINES.

Comparatively few of the coal mines of the country are frankly
acknowledged to be gaseous, and singularly enough, since the
bureau's work was inaugurated in 1908, only a single explosion
disaster has occurred in a mine in which safety lamps were being used
prior to the explosion. The statistics gathered in Great Britain
regarding explosions in districts in which the number of mines using
safety lamps and the number using open lights are about even have
demonstrated that about 90 per cent of the explosions or inflamma-
tions in those districts have occurred in open-light or so-called
"nongaseous" mines.

The reason for far greater immunity from explosions in mines that
are ordinarily considered dangerous because of the presence of fire
damp is that greater care is taken in all respects. Vigilance is not
relaxed, open lights and the use of matches is forbidden, permissible
explosives are used, and the ventilation at the working places, at the
face, and in the pillar workings is carefully maintained.

The Belgian mines are generally acknowledged to be on the average
the most gaseous in the world, yet, as already stated, there has not
been an explosion disaster in them since 1892.

IMPORTANCE OF EFFICIENT VENTILATION.

Good ventilation at the faces and in the pillar workings is a matter
of vital importance in preventing explosions wherever fire damp is
found in any quantity. It is not sufficient to have a great fan, and
send down an immense current of air; the air current must reach the face or pillar workings to be effective. Investigations by Bureau of Mines engineers have shown that in many mines only a third or less of the volume of air passing through the fan reaches the faces; the larger proportion is lost on the way by leakage at doors and stoppings, whereas in the best ventilated mines more than two-thirds of the original current reaches the faces. In many instances branch entries have enough air passing along them, but by reason of there being no stoppings, or very leaky ones in room break-throughs, the air does not sweep the heads of the rooms, where it is most needed.

The remedy is to have all main ventilating doors double or treble, and to put tighter stoppings in the entry cut-throughs or crosscuts. If the stoppings are built of boards, they may be plastered or, preferably, covered with a thick coating of concrete which can be advantageously applied with what has been termed a "cement gun." Put on in this way all cracks are filled and it makes a tight as well as a fireproof stopping. The room break-throughs, except the inner one, should have stoppings or brattices or should be gobbled up, which would effect a great improvement in ventilation at the face.

When a mine is gaseous, it is important to have line brattices up to the faces, and it is equally important that the brattices shall be kept tight and that the curtains shall be kept in place. In one gaseous mine engineers of the bureau saw a machine truck left under a line-brattice curtain, lifting it so that the air current was short-circuited, with the result that fire damp filled the room.

**Small bodies of fire damp should not be neglected.**

The importance of preventing an ignition of even the smallest body of fire damp is not always recognized. Experiments at the experimental mine have shown that the presence of a small percentage of fire damp will render explosive coal dust in the air that otherwise would not be explosive because of a high ash or a high fixed-carbon content as compared with volatile-combustible content. For example, one low-volatile coal dust (77 per cent fixed carbon, 16 per cent volatile combustible) mixed with shale dust was tested at the experimental mine and would not propagate an explosion when there was only 20 per cent of shale dust in the mixture, but when only 1½ per cent of natural gas was in the air current, a violent explosion was propagated by the dust in a mixture with 40 per cent of shale dust. Again, semianthracite dust with as much as 9 per cent volatile combustible (85 per cent fixed carbon) could not be ignited by a blown-out shot, but when 1½ per cent of natural gas was introduced, the dust ignited and propagated an explosion. Moreover, if a considerable body of gas is ignited, it in turn may cause ignition of coal dust that otherwise would be unlikely to ignite. But even the
ignition of a small body may be dangerous; one great disaster was undoubtedly started in this way in an open-light mine. A blower of gas from a clay slip had been liberated by a shot, and shortly afterwards the small body of fire damp that had collected in by the end of the line brattice was evidently ignited by a miner with his open light, who returned to the face probably as soon as the smoke from the shot had cleared up. The evidence seen indicated that the resulting local explosion of fire damp was not violent, but it ignited coal dust and caused a great coal-dust explosion that gained in strength as it swept through intaking entries and returns wherever there was sufficient dry inflammable dust.

**HOW COAL DUST IS MADE IN MINES.**

Now that the danger of coal dust as an explosive agent has been clearly demonstrated, the means of preventing coal-dust explosions must be constantly studied by every mine official. He should give careful consideration to the various methods that have been experimentally demonstrated to be effective in order to select and use those best suited to the conditions in his mine.

Despite all that has been said and written during recent years about the prevention of explosions, it must be admitted that unsatisfactory progress has been made in this country in lessening the number of dust explosions. Why? it may be asked. The observation of Bureau of Mines engineers is that mine managements are not using the means at hand. Out of 100 typical mines examined in one State, only 15 were taking any precautions, and in only a few of these was there enough systematic humidifying or watering to give reasonable assurance that the coal dust, always present in a coal mine, was rendered nonignitable.

In every mine in which a coal-dust disaster has occurred since Federal investigations began in 1908, long stretches of entry were found that seemingly prior to the explosion must have contained coal dust sufficient in quantity and sufficiently dry, pure, and fine to be explosive if raised as a cloud. The purity of the dust was indicated by the samples subsequently gathered.

Of course it is difficult to determine the prior condition of a mine passageway from its condition after an explosion, especially as a violent explosion makes dust by abrasion, but there are characteristics that lead one to decide whether the roadway has been dusty immediately before the explosion.

Perhaps the reason better protection is not sought in bituminous mines in general is that coal dust is everywhere and its presence and danger are frequently forgotten. Coal-dust accumulations must be situated just right with reference to a source of ignition in order to be blown by a blast of air in a thick dust cloud near enough to ignite
from the flame of a shot or burning or exploding gas or an electric arc. The risk of an explosion may seem to a mining man like the chance of being struck by lightning, yet the chances are greater than that, as indicated by the toll of mine explosions in this country, which has varied in recent years from 400 to 1,100 deaths per annum.

CAUSES OF AND REMEDIES FOR COAL-DUST PRODUCTION.

Much may be done toward lessening the risk of coal-dust explosions by diminishing the quantity of dry coal dust produced. This may be done at the face by (1) undercutting the coal and dampening the cuttings by watering with hose or (2) using a minimum amount of explosive. Blasting both makes dust and scatters it proportionately to the excess of explosive used.

If coal dust were found at the faces only, explosions would be limited in extent, but unfortunately it is usually scattered throughout the entry system by one of the following causes:

(a) By pieces falling off the overloaded mine cars and being ground under foot and by the car wheels. The remedy is to have cars with high sides and ends and not to load above the sides.

(b) By pieces of coal and coal dust siftiing through cracks in the cars and around the loose-fitting gates. The remedy is to have tight cars with close-fitting gates, but preferably with tight ends, which, however, will require side-revolving damps, such as are used universally in Europe and in a few mines in Alabama and other States.

(c) By coal fragments falling from the entry ribs and from any roof coal that is left standing. The fallen coal fragments are ground to dust by passing men, animals, and cars. The remedy is more difficult, involving timbering and tightly lagging the ribs, or, preferably, lining the entry with brick or concrete or coating with cement and sand by employing the cement gun. It is also suggested that whitewashing the coal ribs helps to retard spalling and chipping.

(d) By coal dust being carried by the air current from the faces and from mine cars or from the surface screening plant by downcasting shafts. The remedy for the first is to lessen the charges of explosive and improve the haulage arrangements as before mentioned; the remedy for the latter is to move the screening plants to a point more than 100 feet from the top of any downcast shaft; most of the plants of European mines are now so placed and some of the newer ones have suction hoods over the screens to draw off and collect the floating dust.

METHODS OF MAKING COAL DUST INERT.

After one does the best he can to dry clean by shoveling and even by sweeping the coal dust in a mine there would still be enough coal dust in the average coal mine to propagate an explosion once started,
as was strikingly shown by a group of tests at the experimental mine during the winter months when the mine was dry. The mine was cleaned as thoroughly as possible with shovel, brushes, and jets of compressed air, assisted by a strong air current moving in the direction of the cleaning, and then coal-dust zones only a few hundred feet long were arranged near the face of the entry, where the igniting shot was placed; there was no rock dust or other limiting means placed outby the coal-dust zone. In each of the several tests the explosion swept violently through the supposed “dustless zone” 1,000 feet in length and the flame issued from the mouth of the mine in spite of the fact that the entry was much better cleaned than an average mine could be. It therefore is necessary in a dry mine or dry area to do something more than merely brush and shovel up the dust. After the ordinary dry cleaning of an entry with shovels there is often more danger than before if nothing else is done, as the chunks and stones, the coarser dust, and often much uninflammable dust are removed, whereas the fine dangerous float dust remains and, after the removal of the chunks and stones, is more exposed to being swept by an air blast; therefore as soon as a roadway has been cleaned it should be treated by watering or with rock dust.

The use of vacuum cleaners, such as are employed in homes and hotels, has been frequently suggested, but there are many difficulties to encounter in applying the cleaner to irregular surfaces of mine passageways and working places. To be effective every square inch of the surface of the roof, ribs, floor, and timbers must be brushed by the collecting device. A mine vacuum cleaner employing a brush collector with a compressed air jet in the center for displacing the coal dust, and vacuum holes around the rim for sucking it up, has been brought out by a Glasgow (Scotland) manufacturer, but has not yet been extensively introduced in mines, though mechanically good, probably because of the expense of gathering the dust in this way and the grave doubt whether the collecting by any cleaner is sufficiently thorough to avoid the employment of other means of neutralizing coal dust.

Broadly speaking, the only two methods known of treating coal dust to make the mine safe from dust explosion are wetting and covering the coal dust with rock dust or other inert dust.

METHODS OF WETTING COAL DUST

Coal dust is explosive only when suspended as a cloud in the air. So long as it remains on the ground or on the ribs it is harmless; therefore, if the dust throughout a mine is wet so that a concussion will not raise it into the air, there is no danger in that mine of a dust explosion. Merely moistening coal dust is not sufficient. The dust
must be so wet that dust particles will stick tightly to surfaces or stick together, a test of which is whether the wet dust is plastic when molded in the hand. This means that if the coal dust is fine and pure it must contain at least 30 per cent (of the weight of the dust) of mechanically held moisture.

The usual methods of wetting dust are as follows:
1. By a tank car.
2. By a water hose.
3. By calcium chloride or other deliquescent salts.
4. By fixed water sprinklers.
5. By steam jets.

WATERING BY TANK CAR.

Watering by tank car, if the water is forced out by means of a pump, or by compressed air, or by a centrifugal sprayer, so that the roof, ribs, and floor are forcibly swept by the water, is an excellent system. The old form of water car which allowed water to run out through a hole in the bottom of the tank and dribble along the track is useless.

USE OF WATER HOSE.

The method of watering by hose has great merit. If the water lines extend throughout the mine the water may easily be thrown into any opening and the watering be concentrated where most needed; moreover, the equipment does not interfere with mine haulage, as does the water-tank car. If efficiently used it perhaps is one of the best methods there is of watering dust. In recent years it has been most effectively employed in the naturally dry mines of Utah, in which there have been no explosion disasters since that at Winterquarters in 1900, which killed 200 men.

USE OF CALCIUM CHLORIDE AND OTHER DELIQUESCENT SALTS.

The use of deliquescent salts, especially calcium chloride, which has a strong affinity for water, has proved efficient under some conditions, and has been extensively used in a number of mines in West Virginia and in the Pittsburgh district of Pennsylvania. The distribution of dry granulated calcium chloride has been found advantageous in mines where the dust is rather thick in the roadways and in the gobs. The chloride absorbs the moisture from the air current and mats the coal dust together. However, the dry, granulated form does not take care of the dust adhering to timbers, roof, and ribs. These require supplemental sprinkling with water or with a solution of calcium chloride. Common salt with a small percentage of calcium chloride has been used, but investigation has shown it to have little value. Pure common salt (sodium chloride) has so little attraction for water that it is
almost useless as a means of wetting dust. Salt has also been proposed as a substitute for rock dust in dry treatment, but so large a quantity is needed that its use does not seem commercially practicable.

**Fixed Water Sprinklers.**

Fixed water sprinklers at intervals through the mine were at one time thought to offer great promise, but trials in various parts of the country have shown them to be insufficient in themselves. Their range is small, and they are apt to be damaged by drivers or other employees who have to pass them and who do not wish to be wet; further, they are likely to become clogged. Three large explosion disasters and one of lesser size have occurred in mines in which they have been used; also in other mines it has been found that there were long stretches of dry dust between the points where the sprinklers were installed; so, except for supplementary purposes or for drenching the tops of mine cars, they have not proved successful in practice from one cause or another.

**Humidifying the Intake Air.**

Humidifying the intake air to prevent dust explosions is not a new method, having been tried many years ago in South Wales, but did not receive thorough trial until about 1908, when taken up at the Monongah mines of West Virginia. Humidifying the air to saturation is not good for comfort or health if the mines are deep and therefore hot, as are many coal mines in Europe, but the method does not have this disadvantage in the cool atmosphere of most American coal mines.

The humidifying of the intaking ventilating current serves two purposes: It prevents the drying out of the coal dust; and if supersaturation is accomplished, as it should be, a certain amount of moisture is deposited on the walls, floor, and dust. The method is more nearly automatic than other watering methods, seems to be effective, and, in many West Virginia mines, it is claimed that it has not damaged the roof.

There are two systems of humidifying the intake ventilating current: (1) Preheating the intaking air to mine temperature by steam coils and then humidifying it by fine water sprays, or sometimes by the use of wetted curtains; and (2) the use of steam jets. The first system has been used in a number of mines in various parts of the country, but requires a somewhat expensive installation. The second system has been used extensively and is inexpensive to install where there is a blowing fan driven by a steam engine, so the exhaust steam can be used in jets for humidifying the intaking air. The method has been employed in a large number of mines in various parts of the
country—in more mines in West Virginia than in any other State. The exhaust of the fan engine usually supplies enough steam for humidifying, but in the coldest weather may have to be supplemented by live steam.

It was once thought that the heat of steam jets would be very injurious to the mine roof, but it was found that the effect is only local, extending not over 20 or 30 feet from the jets, and is easily protected against by close timbering or arching for this distance.

The excessive heat which might damage the roof is quickly lost, owing to the rapid expansion, and cooling, of the steam when turned into the air current, with the net result, in an ordinary installation, of raising the temperature of the air current only 10° to 15° F. This gain in heat is of advantage in cold weather, when the jets should always be in use. The greater uniformity of temperature and of humidity of the intake air current attainable by proper control throughout the year is more favorable as regards effect on the roof than are fluctuations. In a few mines the method has been accompanied by a system of preheating of air with steam coils. If the intake is on the airways and not on the haulage roads, preheating does not seem to be necessary; but if the intake is on the haulage roads it is of great advantage, because it is important to avoid fogging the air, which would make haulage dangerous.

It must not be assumed that steam humidifying needs no attention. It requires careful watching and regulating so that the proper amount of steam enters. The lower the temperature and relative humidity of the outside air the larger must be the amount of steam entering.\(^a\)

The dust in some mines using the steam-humidifying method has not always been found moist enough. Often the manager does not appreciate that the volume of the steam jets should be greatly increased in cold weather—approximately in inverse proportion to the dryness of the entering air. In many extensive mines there should be supplementary treatment by sprinkling, as moisture from the humidified air is not always evenly deposited. Again, some operators turn on the steam jets only in the winter months, without regard to the possible dryness of the coal dust at other seasons, or perhaps all the year, in some parts of their mines. The only final test is that the dust be wet throughout at all times, regardless of the season.

At the experimental mine tests made to determine the effect of humidifying the air with steam jets showed that if pure coal dust was in small heaps and layers that were undisturbed the dust would not become wet after weeks of testing, but drops would accumulate on the surface of the heaps and from time to time run off without wet-

ting the coal dust, so that although the roof and ribs were damp, and the floor, and the dust that had fallen on the floor were wet, there still remained the small piles and layers of dry coal dust on the projections and shelves. The results of the use of the method in commercial mines indicate that if general cleaning is first done this condition of separate gatherings of dry coal dust does not prevail; that is, the dust that is made along the haulageway falls in small particles on a wet surface and becomes wet, so that there is no opportunity for the collection of heaps of dry dust, which would occur if the mine was dry. Further, owing to the humid atmosphere from supersaturation in the air, the particles of moisture condense around a particle of dust and thus help to precipitate it from the air, just as soot in a smoky atmosphere tends to be precipitated by drops gathering from a fog.

USE OF ROCK DUST TO ASSIST IN WETTING COAL DUST.

Although many of the tests at the experimental mine during the past year demonstrated the successful use of shale and limestone dust for preventing coal-dust explosions, the bureau’s investigators are not prepared to state that, under many circumstances, shale and limestone dust treatment is better than a good watering system. One important fact was discovered while tests of coal dust mixed with rock dust were being made—that although pure coal dust can be thoroughly wetted only with difficulty, when shale dust or limestone dust is mixed with it in equal proportions the mixture absorbs moisture rapidly; in the case of larger proportions of rock dust than coal dust so rapidly that in making tests with mixed dust late in the spring, when the mine was wet, the dust placed on the side shelves and the floor became wet so soon by contact with the wet surfaces as to make a satisfactory explosion experiment difficult. For purposes of coal-dust-explosion testing, the present method of placing the dust on overhead cross shelves was found to overcome the difficulty, but the former trouble suggested a valuable adjunct to the system of watering the mine. It is therefore proposed that, from time to time, shale dust or limestone dust be strewn through the passageways of the mine, particularly in those entries in which the accumulation of coal dust is rapid, to assist in wetting the coal dust with which it is in contact. The greater capillary attraction of mixed dust as compared with pure coal dust has been confirmed by laboratory experiments.

Chamberlin suggested, following his investigations of the Monongah, Darr, and Naomi coal mines in 1907, that the walls of the passage-

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way and props be coated with a mixture of shale, earth, or lime with water, to which coal dust would adhere, and which would bind the particles of coal dust together, and prevent the latter being swept up by air currents. It has also been suggested that such a plaster, or mud, be applied with the "cement gun." These methods have been carefully considered by the engineers of the bureau in connection with the experimental mine tests; but it is believed that the methods, although correct in theory, would not be practicable for use in commercial mines, for these reasons: The employment of the cement gun was found on trial to be too expensive to permit use except for a permanent lining with cement and sand, for which purpose it was found to be efficient and reasonable in cost. The objection to the plaster or mud is that after a short time the constant making of new dust would require the removal of the excess dust; and it appears the only way this could be efficiently done would be by washing the entire coating from the walls. Where watering is thoroughly done, the walls are constantly being washed by force sprinkler or hose. The humidifying process relies on keeping the dust constantly wet. In using dry shale or limestone dust the chief problem is the making of new coal dust, but if additions of rock dust keep pace with the making of coal dust in the proper proportions, a safe condition against propagation of an explosion is maintained.

MAKING COAL DUST INERT BY MEANS OF AN INERT DUST.

The "wet" processes of making coal dust inert have been described. What may be termed the "dry" methods of neutralizing its potential danger are described in the following pages. The dry methods involve the employment of some inert or noninflammable dust that will be brought into the air by any concussion that will raise dry coal dust; the inert dust, by absorbing the heat of any flame present and by separating the individual particles of coal dust by its own particles, will restrict the transfer of heat and flame from point to point, and if the air be sufficiently charged with it for a considerable distance, an explosion will be extinguished.

The process of distributing inert dust through the mine has been somewhat extensively adopted in Great Britain since the experiments at Altofts and Eskmeals have shown the advantage of the system in mines where the operators can not use the watering method, or will not, for fear that it will soften the roof material, often a friable shale, and cause falls.

The source of supply of the inert dust in mines of Great Britain and France generally has been the shale from the roof, shale having as little combustible matter as possible being selected and ground. It has also been considered important that the shale contain little
free quartz, as experience in metal mines has shown that quartz dust is injurious to the lungs. However, the danger of harm from any quartz that might be present in road dust seems remote, as the dust would only occasionally be stirred by haulage and the amount breathed would be nothing like that breathed by miners in quartz mines, where, in drilling upper holes in stoping, clouds of quartz dust are produced unless spraying is employed.

In this country the use of rock or shale dust to prevent coal-dust explosions has made little progress, partly because there is less difficulty in employing the water system than in foreign mines, and partly because the operators and State mine inspectors have not felt sure of its success. So far as known the method has been on trial in only one commercial mine, which is in Colorado. Recently a company working mines in the Pittsburgh district has tried, at the suggestion of the bureau, limestone dust in lieu of water and calcium chloride. So far the results have been favorable both as regards comparative cost and the rendering of the dust in the haulaways treated inert. Incidentally the roadway, ribs, and roof have the appearance of being whitewashed, an advantage for illumination. However, some coal mines in which the shale roof is friable and tends to break down rapidly are safe from the danger of coal-dust explosions owing to large admixture of inert dust from the roof or from the clay floor, which makes the mixture uninflammable. The long-wall mines of northern Illinois are striking examples in their entire freedom from coal-dust explosions, although coal has been mined extensively in the district for the past 40 years.

EXPERIMENTS WITH ROCK DUST AT THE EXPERIMENTAL MINE.

In the course of trying to test all promising methods of preventing explosions, the bureau took up tests to determine what proportion of inert dust in a mixture with coal dust would be required under the severest conditions to prevent the starting of an explosion by a blown-out shot with long flame, and also to determine what proportion would prevent the propagation of an explosion started by a violent initial explosion of pure coal dust.

PROPORTIONS OF ROCK DUST REQUIRED TO PREVENT EXPLOSIONS.

It was found that if there was employed in a mixture with standard Pittsburgh coal dust a proportion of 70 per cent of shale dust ground from the roof shale, or 60 per cent of shale dust from a stratum below the coal bed, which contains only 1 per cent of combustible matter, or 60 per cent of limestone dust, ignition of the mixed dust by a blown-out shot of 4 pounds of black powder would be prevented; and that if the mixture contained 80 per cent of roof shale dust or 75
per cent of either the limestone dust or the shale dust nearly free from combustible matter, propagation from a violent initial explosion of pure coal dust would be prevented. The reason that a little larger quantity of this particular roof shale dust than of the other shale or limestone dust is required to prevent ignition and propagation is that it contains about 10 per cent of combustible matter. Dust from a shale containing little or no combustible matter would be preferable, but as in the Pittsburgh district the roof shale over the coal bed is readily available, whereas other shale may not be, the roof shale was tried. It was recently found that a shale stratum outcropping about 62 feet vertically below the Pittsburgh coal bed at the experimental mine contains less than 1 per cent of combustible matter, and otherwise furnishes an excellent inert dust for explosion prevention. However, if shale of this character is not easily obtainable, and bituminous shale is, the latter can easily be burned before grinding, in a manner similar to burning clay ballast, practiced by certain western railroads, by spreading the shale over a bottom layer of slack coal. Generally, however, an old burned dirt dump is available, and may furnish material free from combustible matter.

**AMOUNT OF COMBUSTIBLE MATTER IN LIMITING MIXTURES.**

The limiting explosibility mixtures of Pittsburgh coal dust may be expressed—differently than as above—on the basis of the total combustible matter present. The 60 per cent mixture of shale or limestone dust for prevention of ignition contains about 35 per cent of combustible matter; and the 75 per cent mixture, which prevents propagation from an initial explosion, contains about 22 per cent of combustible matter. The advantage of this method of expression is to make comparison with dusts of other bituminous coals, which may contain more ash or more moisture than the Pittsburgh coal dust, and would therefore be expected to require less admixture of inert dust to render the mixture nonexplosive. It is of course highly advisable to accept the limit which will prevent propagation, since an initial explosion of gas or fresh coal dust at the face is always a possibility. In general, therefore, the total combustible matter of any sample of dust that may be collected along a passageway of any bituminous or lignite mine should not contain over 22 per cent of combustible matter, if rock dust is used, otherwise the dust should be thoroughly wetted.

Limestone dust, when used in mixtures in the experimental mine, judging from the analysis of the afterdamp collected by the automatic samplers, loses some of its carbon dioxide in the explosion. Although this tends to cool the flame, apparently it is not a sufficient
factor to make a different explosibility limit from that of shale free from combustible matter. If there is a slight difference it is probably offset by the greater specific gravity of the limestone dust over that of the shale dust, which would tend to make it slightly less efficient in rising as a dust cloud.

FINENESS OF ROCK DUST AND COST OF GRINDING.

For rock dusting throughout a mine it is desirable to use a finely ground dust, so that any shock wave which might raise coal dust will easily raise the noncombustible dust. Such dust should be of a fineness so that nearly all will pass through a 100-mesh and 75 per cent through a 200-mesh sieve. Rock dust for overhead barriers may be somewhat coarser but nearly all should pass through a 60-mesh and at least 40 per cent through a 200-mesh sieve.

If the rock-dust process is extensively employed there should be little difficulty in finding a suitable shale for grinding, and the cost should be comparatively small. The limestone dust that was employed in the bureau’s tests was from a quarry in the Pittsburgh district, and, put up in sacks, cost $2.65 per ton f. o. b. the cars at the experimental mine. As limestone quarries are found in the vicinity of most coal fields, and as the dust is usually a waste product, if required in large quantities, it could doubtless be obtained at a lower price than that mentioned.\(^a\)

Shale is easily crushed and ground, and if a well-arranged grinding plant were erected near a mine or group of mines the cost per ton of dust should be small. A grinding plant similar to that of the experimental mine, completely housed, including bins, engine, and machinery, but not including boilers, would cost less than $5,000.

Exclusive of power and delivery charges the cost per ton of dust ground at the experimental mine is about $2, but recent changes in the plant to make it more automatic are expected to reduce the cost to $1 per ton.

APPROXIMATE COST OF APPLYING ROCK DUST.

It is thought that the cost of grinding, handling, and applying, if the shale dust were ground locally on a considerable scale, would not exceed $3 per ton. If the dust were applied at the rate of 5 pounds per linear foot of entry the cost would thus be three-quarters of a cent per foot, or $50 per mile of entry. If 5 miles of mine roadway required treatment—that is, contained coal dust in sufficient amount if raised in the air to be exploable—the total cost of an application would be about $250. The experience in some of the English mines is that the

\(^a\) Circular 167 of the University of Illinois Agriculture Experiment Station states that at most points in Illinois the cost of pulverized limestone delivered in bulk in box cars should be between $1 and $2 per ton.
roadways do not have to be redusted more than two or three times a year; but as coal dust is made more rapidly in American mines it is advisable to consider that there will be required, say, four applications annually; so the cost in a mine of average size would be about $1,000 per annum, and proportionately more in larger mines. It is to be understood this figure is a rough approximation and is meant merely to give an idea as to the cost. Suppose the estimate be increased 50 per cent, and assume that such a mine produces 150,000 tons of coal per annum. The cost of a reasonable insurance against coal-dust disasters would then be 1 cent per ton of coal produced. In considering this cost it must be remembered that nearly all bituminous and lignite mine operators are now put to some expense in trying to prevent coal-dust explosions, and that some of the mines that take especial care expend on the watering method as much as 1 cent per ton of coal produced. The figures reported for the cost of using the rock-dust method in certain British mines are less than one-half cent per ton, but, as the conditions as regards the daily production and distribution of coal dust are less severe, and as labor costs less, it would not be safe to accept costs in those mines as applicable to mines in the United States.

In considering the relative advantages and disadvantages of the method in comparison with some good wetting system, it must, of course, be remembered that the conditions vary widely as to the production of coal dust in different mines; and it is manifest that if coal cars are continually dribbling coal dust, and much coal falls from the tops of cars, the figures above specified would not be large enough. Rock-dust treatment can be really efficient only when by good management the amount of coal dropped along the roadways is kept within reasonable bounds. The amount of time and energy required to take care of the coal that is dropped along the roadways is not always appreciated by the operators. In one mine it was observed by the bureau engineers that six men were kept constantly employed shoveling up coal along the roadways. Under such conditions it is manifest that neither the rock-dust treatment nor any other could be made thoroughly effective. If tight cars were introduced in this mine, and their loading not carried above the sides of the cars, little coal would fall along the roads, and though the mine car investment would be increased, the large amount expended for cleaning would be curtailed, and this saving would help if not fully provide for efficient protection from dust explosions.

One of the most advantageous features connected with the employment of rock dust is that it is visible, and its value will not be destroyed in a day, as may happen if watering is neglected.
METHOD OF APPLYING ROCK DUST.

The first operator to systematically employ rock dust and advocate its use for the prevention of coal-dust explosions was Sir William E. Garforth, who first applied it underground at the Altofts colliery in 1908. His method of application has been to have the rock dust thrown on the walls by hand, enough force being used to dislodge any coal dust, and to fill in crevices. The rock dust lodges on all ledges and timbers, as well as the floor, and to some extent sticks to the walls. In a Colorado mine, adobe dust has been applied along a trolley road by means of a special car on which there is a blower electrically driven, the return being connected to a bin on the car holding dust. The dust is ejected through a hose pipe, making a dense cloud in the air blast. This seems a cheap but effective way of dislodging coal dust and filling crevices with inert dust. Moreover, the finest inert dust is floated along with the air current, and deposited naturally on the ledges and floor. However, the application by this particular machine is limited to the trolley road, but it would not be difficult to arrange a car with a blower fan, driven from the wheels by gear or belt, for haulage by mules, or a blast from a compressed-air tank could be used. In any case the car should be hauled against the ventilating current so the attendants do not have to breathe in the dust cloud.

Further experience under American mine conditions is needed to determine the best manner of placing the rock dust. For the present the bureau recommends throwing the dust forcibly in recesses, on projections, and on timbers supplemented by cross shelves, besides spreading the dust on the floor.

CHARACTER OF ROCK DUST FITTED FOR USE IN PREVENTING EXPLOSIONS.

Apart from the comparatively small danger to health occasioned by the use of quartz and similar dusts, almost any inert dust that is fine enough to rise in a cloud will be effective. It has been suggested that soil or earth might be used. In the British testing gallery flue dust and fuller’s earth have been found to be good materials, but the bureau has thought best to test only such materials as can be readily obtained in quantity in American coal-mining districts.

The principal difficulty in using soil or dirt—except adobe dust, which may usually be gathered dry in the arid districts of the Rocky Mountain region and which was suggested to some of the operators of the district following the Primero disaster of 1910—is that such inert material must be dried and powdered in order to be effective except as it is used to cover up coal dust on the floor. In the Courrières mine of France, where happened the greatest explosion disaster in the history of coal mining, it is now the practice to bring in fresh
clay every few months and lay it along the roadways. The clay is damp and plastic, so serves as a coal dust collector, pieces of coal and coal dust dropped along the roadway being tramped by the traffic into the clay. When observation and test show that the clay is too full of coal dust to be safe it is removed and fresh clay is spread along the roadway. The same object could be attained by the use of ashes free from combustible matter. Though these methods are good for track ballasting, they do not provide for neutralization of coal dust on the rib projections or in recesses and on timbering. In the long run, therefore, where it is desired to use the rock-dust method, it will be best to erect a crushing and grinding plant like that at the experimental mine unless limestone dust can be cheaply obtained.

**ROCK-DUST BARRIERS.**

**ORIGIN AND GENERAL CHARACTER.**

As a supplementary means of stopping explosions that have started in spite of precautionary measures, the so-called "rock-dust barriers" have been investigated at the experimental mine. They are not intended in any way to take the place of any of the preventive means but must be regarded only as secondary safeguards.

The use of rock-dust barriers, apart from the general application of rock dust, was primarily due to the investigations of J. Taffanel, director of the French mine-testing station at Liévin. He found that by blockading the testing gallery with a pile of earth filling over one-half of the cross section of the gallery he could block or extinguish an explosion. As such a barrier was not practicable in mines, he then evolved the method of employing a group of shelves across and over the roadway laden with shale dust or ashes, which have been termed "Taffanel barriers"; on such shelves there was concentrated a large enough amount of rock dust to extinguish any coal-dust explosions that he tried in the testing gallery. Originally the number of shelves that he employed in a single "barrier" was 10, each 20 inches wide, placed 2 yards apart, and loaded with either fine shale dust, rock dust, or ashes, as high as could be piled, the shelves being so placed that there was a little space between the piled dust and the roof. Subsequently his experiments indicated that it was necessary to increase the number of shelves to 15.

In the bureau's experimental mine the Taffanel shelves were first used in an effort to localize certain experimental explosions, and it was found that they were almost uniformly successful with the moderate and violent explosions, but that the flame of a light explosion, or what might be termed an inflammation, would sometimes pass. This is thought to have occurred with one 10-shelf barrier in a passageway traversed by an explosion in the Clarence mine, France, in 1912. In
view of these instances, the bureau representatives tried to design other devices that would be more sensitive. In planning these consideration was given to the desirability that the barriers should be of such design that they might be used with advantage not only in mines where rock-dust treatment is employed but also in mines where watering methods are used. This requirement called for inclosure of the rock dust so that it might not become moist or wet and thus be prevented from operating successfully.

**Types Developed by the Bureau.**

Accordingly one of the authors devised certain types of barriers some of which have been extensively tested with favorable results during the past year. Application for patents has been made by the designer, George S. Rice, for assignment to the bureau, so that any citizen of the United States may freely use the patents.

Six types of barriers were designed, as follows:
1. Box barrier (consisting of 6 to 8 individual boxes).
2. Concentrated barrier.
3. Rock-dust ventilating stopping.
4. Rock-dust-protected ventilating door.
5. Rock-dust-protected overcast.
6. Trough rock-dust barrier.

**Objects of the Different Types.**

The first four types have been repeatedly tested at the experimental mine and, in the final forms, were almost uniformly successful. The first two are for employment in every ventilating split near the entrance and elsewhere at intervals of one-quarter of a mile in all entries or headings in which coal dust is found. The placing of the third, fourth, and fifth types is implied by their names.

The underlying principle of the operation of the barriers, in common with that of all rock-dust barriers, is to launch a mass (2 to 5 tons) of rock dust or other finely ground noninflammable dust into the air blast that always precedes a dust explosion and to which the possibility of a dust explosion is due. The air blast, termed by the English "the pioneering wave," by its eddying currents mixes the noninflammable dust with the coal dust, so when the flame of the explosion reaches the dense cloud of dust, in which inert dust greatly predominates, the latter extinguishes the flame by absorbing heat; also, on account of the large amount used, doubtless each particle of coal dust is surrounded by many particles of inert dust, which thus form a screen between the flame and the coal dust. The flame of the explosion is sometimes immediately extinguished, but a distance of 50 feet or thereabouts may be traversed before the inert dust borne by the explosion wave extinguishes all the flame.
The second requirement, which is met by each of the designs, is that a barrier shall be operated by a slow-moving, nonviolent explosion. Slowness of movement due to lessened inflammability of the dust encountered in the passage of the explosion through some entries is more often the condition, even in great disasters, than of continuous violence. It is recalled that in one disaster in Colorado an explosion that started near the entrance, after showing much violence in a dusty old main haulage entry, ran inby along a connecting entry containing dust of less inflammability with so little violence in some stretches that it was difficult to tell that an explosion had passed. Even a shovel leaning against the rib was undisturbed, yet farther inby the explosion again developed great violence.

The box barrier and the concentrated barrier are particularly sensitive. The concentrated barrier may also be operated by additional tripping vanes, 100 feet or so in advance, to insure operation by the slowest-moving explosion. Velocities of flame as low as 100 feet per second have been recorded as compared with twenty times this speed in a fast, violent explosion and thirty, or more, times this speed in what may be termed a "detonating" explosion.

When the explosions are violent, giving pressures of, say, more than 30 pounds per square inch, any one of the barriers will be torn to pieces, and the rock dust, being instantly mixed by the fast moving blast, will quench the flame.

The third requirement to be met is that, should the device be operated by an advance air wave far in advance of the flame of the explosion, or by the flame coming from another circuit of the explosion, some rock dust shall be retained on certain parts of the barrier in addition to what may be scattered along the passageway. This has been accomplished by having shelves hung by chains fastened to the roof, or, in the case of the rock-dust-protected ventilation stopping, by open shelves held by posts.

The fourth requirement that was met in the designs was that the rock-dust containers should be inclosed so that the rock dust should not become wet in mines where humidifying or watering is practiced, and to prevent the dust from being contaminated by floating coal dust.

The fifth, applying only to the box barrier, the rock-dust-protected door, and one of the two concentrated barriers, was to provide that in case of accidental tripping, anyone passing should not be seriously injured. The requirement was met by limiting the fall of the heavy parts by means of chains hung from the roof or overhead timbers. The other devices do not need to meet this requirement, owing to the nature of their position or construction.
KIND OF DUST TO USE IN BARRIERS.

The freer the dust used in the barriers is from combustible matter the better it is; also the finer ground it is the better it is for the purpose of making a dust cloud and of being borne along by the current with the coal dust. The specific gravity, or weight, of the particles in comparison with equal-sized particles of coal dust seems to be of less importance than for dust used in continuous treatment along the roadway, as in the barriers it falls from overhead and does not have to be raised into suspension. The dusts tried at the experimental mine in the barriers are shale dust and limestone dust, but doubtless many other kinds of fine inert or incombustible dust would be equally effective.

THE BOX BARRIER.

CONSTRUCTION.

The box barrier, as is indicated by the name given it, consists of six or more boxes containing incombustible dust, open topped except for a loose waterproof cover, hung loosely from roof supports 2 to 3 yards apart and extending across the entry near the roof in such a manner that the explosion wave will cause them to be upset, thus throwing into the entry a large amount of incombustible dust. The bottom boards of the box are so arranged that after a short fall they are caught by chains attached to the roof, some of the dust being retained on these boards. Two grids within the box, which rest loosely on blocks and are connected to the same chains at distances of 3 and 6 inches below the top of the box, also retain some of the dust and allow the balance to fall through the open spaces. The boxes are hung high enough to be clear of traffic, a requirement that in a thin coal bed may necessitate the roof being "brushed" or ripped down for a distance of 50 or 60 feet.

Plate I shows the arrangement and the details of construction of one of these boxes (model C). The boxes, as used at the experimental mine, are about 7½ feet long by 23 inches wide by 10 inches deep, and each box will hold 700 to 800 pounds of rock dust. The length and number of boxes required will vary with the cross section of entryway. In the experimental mine the entries average 9 feet wide and about 6½ feet high. It is recommended that not less than six boxes, or, in a very high entry, seven or eight boxes hung at different heights, be used.

Each box consists of a side frame of inch boards with three longitudinal wooden strips, 1 (Pl. I), on the bottom, one at each side, and one in the middle. Loose bottom boards, 2, extend over the two spaces between the strips. At each end of the box is a wooden cross-piece, 12, attached to the underside of the frame. Secured to the
For entry 9 feet wide

Note.—To prevent accidental operation of barrier by passing men or high mine cars, erect guard planks across entry in, out, and between boxes, about 1 inch below bottom.

ARRANGEMENT AND DETAILS OF CONSTRUCTION OF BOX BARRIER, MODEL C.
underside of these wood pieces are steel bars, 3, with hooks at each end extending beyond the sides of the box. These hooks rest in the eyes of supporting rods, 4, which also have eyes on the upper ends to engage over the horizontal arm of hooks, 5, set in the roof or in timbers if the roof is timbered. The horizontal arms of the hooks extend in a direction away from the box and each other. The supporting rods, 4, diverge slightly in an upward direction and so tend to hold the eyes against the vertical arms of the hooks. Short wooden blocks, 6, are nailed to the side frame of each box near the top, so as to reduce to three-fourths of an inch the open space through which the box must swing before striking the rods. Two chains, 8, are attached to a suspension strap, 7, at the edges of each end of the bottom boards. Each pair is attached to an eyebolt or hook, 9, in the roof or overhead timbers.

In the latest form, model C, there are two supplementary grids, 13, connected to these same chains, 3 and 6 inches below the top of the box, by means of heavy wires. Each grid consists of three strips 1 inch by 1$\frac{1}{4}$ or 2 inches, with 2-inch spaces between them. The ends of each grid rest on loose blocks while the box is in normal position. The chains from the grids to the roof hooks have 2 to 3 inches slack. This arrangement permits the box to swing without the checking action tight chains would give. The part of the chains from the grids to the bottom boards is so arranged that when the box frame supports release, and the grids fall 2 inches, the bottom boards beneath them also fall to positions 2 and 8 inches below their original positions. The arrangement of the grids prevents the dust falling in a mass, if packed together, but breaks it up and lengthens the time through which dust is falling through the mine entry.

Inasmuch as the dust may become wet if the boxes are placed in a wet part of the mine, or if steam humidifying or sprinkling is practiced, the tops of the boxes should be covered with waterproof coverings hung from roof supports. Planks are placed across the entry at each end of the barrier just below the level of the bottom of the boxes so as either to displace the coal from a car if piled to such a height as to be likely to strike the barrier, or to warn persons of their proximity to the barrier.

**METHOD OF OPERATION.**

If an explosion occurs, the advance air wave causes the box to swing in the direction in which the explosion is advancing until the blocks, 6, strike against the supporting rods on that side and push the eyes from the supporting hooks, causing the frame of the box to swing from the opposite hooks downward, permitting the dust to be discharged in a shower. The pendulum-like arrangement makes the
boxes sensitive to the movements of air caused by the lightest explosion. Invariably it has been found that if an explosion has reached the boxes they have operated, and with rare exceptions even the earlier types have extinguished the flame of the explosion.

In a light explosion, when the frame falls the grids and the bottom boards suspended by the chain hangers retain a portion of the rock dust, the larger part of which cascades from shelf to shelf and is gradually spilled into the entry in a continuous shower for eight or more seconds. The projection of this dust by the air current forms a thick cloud, extending through the entry for a considerable distance. In an extremely feeble explosion the swinging shelves retain a large amount of rock dust, available for checking a secondary or prolonged flame, which is more likely to occur with a slow explosion than a fast, violent one.

If the explosion is violent, the boxes, including the hanging shelves and bottom boards, are instantly broken to fragments and all of the rock dust is projected in a dense cloud, effectively quenching the flame.

Plate II shows a barrier of six boxes installed in an entry of the experimental mine previous to an explosion test. The details of the supporting arrangements are clearly shown.

Plate III, A, shows a box of model C type on the surface at the experimental mine after it had been dumped. The shelves, with their heavy dust deposits, are at different elevations, and so are in a favorable position for the air currents to blow the dust off and form a thick cloud.

RESULTS OF TESTS.

Plate IV, A, shows the appearance of a box barrier after a very light explosion. It can be seen from the appearance of the boxes on the floor that there was just sufficient pressure to drop the boxes to the floor and they were damaged very little. A large amount of the dust was retained on the shelves, and would have been available to check a secondary explosion had one occurred.

Plate IV, B, shows the appearance of the barrier after a somewhat stronger explosion. The boxes are more broken up and some of the shelves are broken. Little dust remains on the shelves.

Plate V, A, shows the appearance of a box barrier after an explosion more violent than that after which Plate IV, B, was taken. Fragments of the boxes were thrown a considerable distance out by the position of the barrier. The shelves were broken and only fragments remain suspended. The dust on the floor is seen to be evenly distributed. In this barrier the boxes were hung by having the hooks of the supporting rods inserted in stirrups set in the roof,
BARRIER OF SIX BOXES IN MINE ENTRY. ROCK DUST IS PROTECTED BY OILCLOTH COVERS. THE WIRING AT THE UPPER RIGHT-HAND CORNER IS NOT PART OF THE BARRIER.
A. VIEW OF BOX BARRIER, MODEL C, AFTER DUMPING.

B. TYPE B CONCENTRATED BARRIER IN POSITION IN MINE ENTRY.
A. **VIEW SHOWING EFFECT OF LIGHT EXPLOSION ON BOX BARRIER.**

B. **VIEW SHOWING EFFECT OF STRONG EXPLOSION ON BOX BARRIER.**
some of which can be seen in the illustration. The later method, by which eyes are used with hooks in the roof, is preferred to this arrangement of hooks inserted in stirrups.

**THE CONCENTRATED BARRIER.**

The concentrated barrier, as its name implies, consists principally of two large but shallow containers of incombustible dust placed overhead across the entry way and supported near the roof by hinges and catches. The latter in turn are held by a leverage system so adjusted that the system is released when the pressure of an advancing air wave, operating against swinging vanes, reaches a predetermined amount. The vanes are hinged planks 100 feet or more from the barrier on either side, the pressure being converted into a pull by a chain passing around a pulley and transmitted by a strong wire from the chain to the releasing mechanism.

When the catches are released the hinged containers swing quickly downward under the heavy load of rock dust.

**TYPE A CONCENTRATED BARRIER.**

Two different forms of containers have been designed and tested, with successful results. In one form, called the A type, the bottom boards and cross boards, or shelves, of each compartment are nailed fast to its sides and ends. The container is hinged at one end, the other end being free, when its catch is released, to swing to the ground. The box, if not wrecked by a violent explosion which would release automatically all its dust, would then remain at an angle of about 45°, blocking the passageway and retaining about one-third of the dust load on its cross shelves. The duplicate container will have similarly swung down in the opposite direction, forming with the first container an inverted V shaped obstacle across the entry way.

This arrangement is particularly favorable in the case of a very light explosion, as the entry will be practically blocked from either direction, and with dust on cross shelving in readiness to extinguish a delayed or secondary flame.

Plate V, B, is an end view and Plate VI is a side view of a type A barrier that has operated. The boxes were slightly damaged, yet a large amount of dust was retained on the cross boards. The disadvantage of this type of container is that if operated when a person happened to be passing under it, he might be seriously injured. Its use should, therefore, be confined to those entries not regularly traversed by employees, except examiners and officials, such as airways, and connections between panels or different divisions of a mine. In many disasters, if the explosion could have been stopped
in a connecting entry or passage, many lives would have been saved. At the top of Plate V, B, is shown an auxiliary swinging vane (see also 11, Pl. VII); wires from the advance vane pass overhead (see Pl. VII).

**TYPE B CONCENTRATED BARRIER.**

In the second or B type of concentrated barrier the bottom boards are not fastened to the sides and ends and the frame does not fall with the bottom boards, but remains attached to the main timber framework. Each bottom board is separately hinged to a central timber, the other or free end of each resting on a hinged angle iron. When the catches are released the angle iron drops, releasing the boards; these swing down to various distances until caught by tether chains attached to the roof or overhead timber. A thick shower of incombustible dust is thus discharged into the path of the explosion which has operated the barrier, the shower continuing for some seconds if the explosion is delayed or is very light, but if the explosion is violent and consequently fast moving the barrier will be broken to pieces and then all the dust will be launched into the air and scattered over a great length of entry.

The type B concentrated barrier is more generally applicable than the type A barrier, as in case of accidental tripping a person caught underneath would be struck by a single plank hinged at one end, the free end falling at most only 18 inches. It is true this might give a severe blow, but it should not cause a serious injury. Also, the chances of such an accident would be so remote they would seem to be negligible.

There is no difficulty in arranging this barrier over an electric trolley road.

**DETAILS OF CONSTRUCTION OF TYPE B CONCENTRATED BARRIER.**

The outward appearance of either type of barrier is the same and they have similar operating mechanisms.

Either type of concentrated barrier, as indicated above, has two platforms or containers of dust and two sets of levers and vanes that are set up symmetrically with reference to the middle point of the barrier. Plate III, B, shows the barrier in position in a mine entry. In Plate VII the lower view shows an elevation through the center line of the barrier, showing a complete set on one side of the middle support of the barrier and a part of the compartment on the other side; the upper view shows a plan of the same part of the barrier. Plate VIII shows certain of the parts in detail. Data regarding the parts shown in the two plates are shown in the table following:
A. VIEW SHOWING EFFECT OF VIOLENT EXPLOSION ON BOX BARRIER.

B. END VIEW OF TYPE A CONCENTRATED BARRIER, AFTER DUMPING.
SIDE VIEW OF TYPE A CONCENTRATED BARRIER, AFTER DUMPING.
# Data regarding parts of type B concentrated barrier.

<table>
<thead>
<tr>
<th>Piece number on Plates VII and VIII</th>
<th>Name of piece</th>
<th>Material</th>
<th>Number of pieces required</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hanger</td>
<td>Steel</td>
<td>12</td>
</tr>
<tr>
<td>2</td>
<td>Fulcrum pin</td>
<td>do</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>do</td>
<td>do</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>Angle or guide block</td>
<td>Steel or wood</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>Fulcrum bracket</td>
<td>Steel</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>Release bar</td>
<td>Steel and brass</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>Tripping lever</td>
<td>Steel</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>Bracket</td>
<td>do</td>
<td>4</td>
</tr>
<tr>
<td>9</td>
<td>Pivot or hinge connection</td>
<td>do</td>
<td>4</td>
</tr>
<tr>
<td>10</td>
<td>Connecting strap</td>
<td>do</td>
<td>4</td>
</tr>
<tr>
<td>11</td>
<td>Vane (wood)</td>
<td>Wood and steel</td>
<td>2</td>
</tr>
<tr>
<td>11a</td>
<td>Vane strap</td>
<td>Steel</td>
<td>16</td>
</tr>
<tr>
<td>12</td>
<td>Hanger brace</td>
<td>do</td>
<td>4</td>
</tr>
<tr>
<td>13</td>
<td>Shovel hanger</td>
<td>do</td>
<td>4</td>
</tr>
<tr>
<td>14</td>
<td>Vane hanger</td>
<td>do</td>
<td>8</td>
</tr>
<tr>
<td>15</td>
<td>Shovel pin</td>
<td>do</td>
<td>2</td>
</tr>
<tr>
<td>16</td>
<td>Sheave</td>
<td>Cast iron</td>
<td>2</td>
</tr>
<tr>
<td>17</td>
<td>Support arm</td>
<td>Steel and wood</td>
<td>2</td>
</tr>
<tr>
<td>18</td>
<td>Vane</td>
<td>do</td>
<td>2</td>
</tr>
<tr>
<td>18a</td>
<td>Vane plate</td>
<td>Steel</td>
<td>2</td>
</tr>
<tr>
<td>19</td>
<td>Angle iron</td>
<td>do</td>
<td>2</td>
</tr>
<tr>
<td>19a</td>
<td>Hinge connection</td>
<td>do</td>
<td>2</td>
</tr>
<tr>
<td>20</td>
<td>Dust check</td>
<td>Galvanized iron</td>
<td>4</td>
</tr>
<tr>
<td>21</td>
<td>Side frame</td>
<td>Wood</td>
<td>6</td>
</tr>
<tr>
<td>22</td>
<td>Hinge</td>
<td>Steel</td>
<td>18</td>
</tr>
<tr>
<td>23</td>
<td>Collar</td>
<td>Wood</td>
<td>1</td>
</tr>
<tr>
<td>24</td>
<td>Cross timber or collar</td>
<td>do</td>
<td>2</td>
</tr>
<tr>
<td>25</td>
<td>Bumping block</td>
<td>do</td>
<td>2</td>
</tr>
<tr>
<td>26</td>
<td>Support wire</td>
<td>do</td>
<td>2</td>
</tr>
<tr>
<td>27</td>
<td>Chain</td>
<td>do</td>
<td>2</td>
</tr>
<tr>
<td>28</td>
<td>Collar</td>
<td>Wood</td>
<td>2</td>
</tr>
<tr>
<td>29</td>
<td>Guards</td>
<td>do</td>
<td>2</td>
</tr>
<tr>
<td>30</td>
<td>Bottom plank</td>
<td>do</td>
<td>4</td>
</tr>
<tr>
<td>31</td>
<td>Chain</td>
<td>Steel</td>
<td>18</td>
</tr>
<tr>
<td>32</td>
<td>Galvanized wire</td>
<td>do</td>
<td>2</td>
</tr>
<tr>
<td>33</td>
<td>Chain</td>
<td>do</td>
<td>2</td>
</tr>
<tr>
<td>34</td>
<td>Chain pulley</td>
<td>do</td>
<td>2</td>
</tr>
</tbody>
</table>

* For use in type B only, other parts common to both barriers.

The dust compartments each measure 7 by 7 feet by 12 inches deep and together will hold about 3½ tons of limestone dust. The bottom of each compartment consists of a number of unconnected and separately hinged planks a to i (Pl. VII), with a side frame, 21, of 2-inch plank touching the bottom planks, but spiked to the main frame so as not to fall when the bottom boards are released. Each of the bottom planks is attached by a hinge, 22, to the middle cross timber or collar, 23, which separates the two dust compartments. The free ends of the planks of each compartment are held up, when the planks are in the normal horizontal position, by an angle iron, 19 (Pls. VII and VIII), bolted to four steel arms, 19a (Pl. VIII), which are pivotally supported by bolts through cross timber, 24 (Pl. VII).

## DETAILS OF CONSTRUCTION COMMON TO TYPE A AND TYPE B.

### METHOD OF OPERATION.

The angle iron is maintained in a position supporting the planks through a system of levers, 17, 6, 7, which are pivotally supported from cross timbers or collars. Levers 17 and 6 reduce the load
thrown on the tripping lever 7 so that it can be easily shifted by the wires from the vanes, causing the barrier to dump. The short arm of lever 17 engages under the angle iron, and the long arm rests beneath the short arm of lever 6. There are two angle brackets preferably of brass or other noncorrosive metal on the sides of this lever near the end of the long arm, the under surfaces of the horizontal flange of which are curved upward. Lever 7, called the trip lever, is two-pronged at the lower end and the ends of the prongs are turned in horizontally toward each other. The horizontal surfaces engage under the curved surfaces of the brackets and serve to hold the lever in a horizontal position until the trip lever is pulled one way or the other. The contact between lever 7 and lever 6 is shown in Plate VII.

A small movement of lever 7 in either direction causes it to disengage from lever 6, which withdraws the support from lever 17 and the angle iron, resulting in the dropping of the free ends of the dust compartments. In the type B barrier, the bottom planks are not permitted to swing to the floor, but are caught by stay chains attached to hooks in the roof or cross timbers. As arranged in recent tests at the experimental mine alternate planks drop 18 inches, the intermediate planks having a drop of only 9 inches. The arrangement of adjacent planks at different elevations allows a considerable quantity (about one-fourth) of the rock dust to fall from the planks and to continue to sift between them for several seconds, the remainder of the dust being held on the planks to be brought into action by the waves immediately preceding the flame or actual explosion. The reason for using the chains is twofold. First, to prevent serious injury to an employee in case of accidental tripping. Second, the checking of the planks in the positions shown by the dotted lines in the lower view in Plate VII tends to prolong the period in which the dust is sifting into the air current, and also causes a considerable amount of dust to be retained on the planks. It frequently happens that the first advance air wave will trip off the barrier mechanism by means of the vanes some time before the flame of the explosion reaches the barrier; in such an event, the prolonged showering of the dust together with that retained on the planks will provide the necessary amount of rock dust to extinguish the flame when it arrives. A violent explosion will demolish the barrier framework and launch all the dust. The flame of a violent explosion quickly follows the advance air wave so the rock dust will be where it will be most effective—that is, in the air.

Three cleats or dust checks (20, Pl. VII), nailed to each plank assist in retaining dust on the planks when the planks fall from their original position. The bottom of each dust check has a small opening that permits a gradual flow of dust from it and thus increases
Chain free end of boards to cross beam so that boards a, c, e, g, and i can drop 18 inches, and so that boards b, d, f, and h can drop 9 inches.

PLAN AND ELEVATION OF TYPE B CONCENTRATED BARRIER.

For description of parts see table on page 29.
DETAILS OF METAL PARTS OF TYPE B CONCENTRATED BARRIER.

For description of parts see table on page 29.
the length of time during which dust is falling from the inclined planks.

The operation of the trip lever 7 can be caused by any one of the advance vanes 11 or 18, hung at various selected distances in advance of the barrier. Vane 11 has attached to it a bumping block, 25, the other end of which is supported by a wire, 26, to the roof. When an explosion wave moves this vane toward the barrier, the bumping block pushes the lower end of lever 7, causing it to disengage from lever 6.

In some rapidly moving explosions this operation might not be quick enough so that the barrier would fall in time to quench the flame; to provide for such explosions, vane 18 is hung about 100 feet in advance of the barrier, one on either side. Attached to the under-side of vane 18 is a chain, 27, which passes around a sheave, 16, and is then attached to a wire that is secured to the top of the trip lever, 7. When vane 18 is swung toward the barrier the motion is reversed by the pulley arrangement and the top of lever 7 is pulled away from the barrier causing its disengagement from lever 6. To provide for instances when vane 18 might be out of order, or if an explosion developed between it and the barrier, similar advance vanes connected by chain to the same wire may be placed at intermediate points.

A wire or chain from the top of lever 7 passes over the dust compartments and is fastened to a chain which, passing around two small pulleys attached to beam 28, is connected to the lower part of lever 7 of the opposite compartment and, when pulled, causes that lever to disengage from lever 6 on that side. Both levers would thus be operated by the same means. At points beyond lever 7 on the far side of the barrier are vanes similar to vanes 11 and 18 and connected in a similar manner to the trip lever on that side of the barrier, thus enabling the barrier to be operated by an explosion coming from either direction.

A plank is placed across the entry beneath each vane to serve as a guard to prevent the barrier from operating through being struck or pushed accidentally.

RESULTS OF TESTS.

Plate IX shows the appearance of the barrier after a light explosion. The planks have all been caught by the chains and have retained much of the dust. The depth and the position of the dust beneath the barrier are clearly indicated. In this explosion a match fastened to a peg in the roof 15 feet beyond the barrier was not ignited, indicating a quick quenching of flame. The photograph was taken looking in by toward the origin of the explosion.

77912°—15——3
The appearance of the barrier after a more violent explosion test, can be seen in Plate X, A. In the foreground is the bumping vane with the bumping block hung from it. In the background can be seen the cross timbers and the planks, which were thrown 15 to 30 feet from their original positions. The even distribution of dust on the floor can be noted in the foreground, the black patches being footprints of persons who have walked through the entry between the time of the explosion and the time the photograph was taken. This photograph was taken looking outby in the direction the explosion went.

DETAILS OF TIMBER AND FRAMEWORK.

Five crossbars or collars are necessary in the construction of the barrier. These can be set in grooves in the rib or on posts as in an ordinary timber set. The collar 23 (Pl. VII), as used at the experimental mine, is a 10 by 12 inch timber, whereas collars 24 and 28 are each 8 by 12 inches. The two timbers 24 (only one of which is shown in Pl. VII) and timber 23 are placed at an equal elevation at a height at least sufficiently great to avoid being struck by loaded cars. The two timbers 23 (only one of which is shown in Pl. VII) are placed 2 inches above the elevation of timbers 24 and 28, to allow the lever 17 to swing through an angle great enough to permit the unobstructed fall of the plank of the dust compartment.

The device as constructed at the experimental mine and tested in the experimental explosions contained approximately 3 ½ tons of limestone dust. The entry at the point at which the device was placed has a cross section of 63 square feet; the dust load, therefore, was equivalent to about 110 pounds per square foot of section. If the cross section of the entry in which the device is to be used varies materially from that given, the proportions of the dust compartments should be changed to give the same ratio of loading to a square foot of section, so as to insure effective operation in the event of an explosion.

ROCK-DUST-PROTECTED MINE-AIR STOPPING.

Whenever there has been an explosion of any extent almost invariably the stoppings have been thrown down. In fact, it is impossible to build at reasonable cost a masonry or concrete stopping unless the stopping is reinforced with iron that will withstand an explosion pressure of over 100 pounds per square inch. The reason is evident, for as the exposed surface is large the total pressure is great. For example, with a pressure of 100 pounds per square inch and a stopping having a superficial area of 50 square feet, a total pressure of 360 tons would be applied with a hammer-like blow.
VIEW SHOWING EFFECT OF LIGHT EXPLOSION ON TYPE B CONCENTRATED BARRIER.
4. VIEW SHOWING EFFECT OF VIOLENT EXPLOSION ON TYPE B CONCENTRATED BARRIER.

B. ROCK-DUST-PROTECTED STOPPING, BEFORE CURTAINS ARE HUNG.
As the failure of stoppings in crosscuts or cut-throughs permits the passage of flame to parallel entries in many explosions, which otherwise might have been confined to a small area, the design of some form of rock-dust barrier, in connection with stoppings at certain points, seemed desirable. The device as designed can be used in connection with any form of mine stopping; or for the usual masonry or wood stopping confined rock dust may be substituted.

CONSTRUCTION.

The device consists of a series of shelves one above another, set up on either side of any kind of a stopping, and loaded with rock dust, or, if there was no stopping at the place where the device is set up, rock dust may be piled between the two sets of shelves. When a strong explosion strikes such a stopping, either the stopping as a whole goes out, discharging the rock dust in a cloud, or the stopping proper, the solid part, is blown out, upsetting the shelves on the far side. In a light explosion it is expected that if the shelf posts on the near side of the stopping are firmly set, they may remain in place even though the solid part of the stopping blows down, and then the explosive blast would blow the dust from the shelves, producing a thick dust cloud which would quench the flame. It is particularly difficult to check or stop a light explosion in which the flame is delayed, yet the danger to life from a light explosion is as great as from a strong one. The arrangement of rock-dust shelves is designed to extinguish the flame of either a light or a strong explosion which may pass into the crosscut or cut-through.

Figure 1 shows a plan of the shelves on both sides of a stopping, a front elevation, and a vertical transverse section showing the sets of shelves with the space between filled merely with rock dust instead of brick, concrete, or wood, or some other stopping material.

METHOD OF ERECTION.

Six posts in two rows of three each are firmly wedged in place on either side of the stopping, the two rows being 12 inches apart. Cleats are nailed to each pair of posts at vertical intervals of 1 foot, and on these are placed boards 12 inches wide to act as shelves. Four-inch strips are placed inside of the posts along the front of the shelves to assist in holding the rock dust in place. When the shelves have been loaded with as much rock dust as the angle of repose of the dust will permit, short curtains are hung from the top of the shelves to just beneath the upper edge of the front strips to protect the dust from becoming wet. The object of not using a large single curtain is twofold—first, the use of separate curtains makes it easier to inspect all parts of the stopping; second, a single curtain would act
like a sail and cause the barrier to go out as a whole, whereas in an explosion the canvas flaps offer little resistance and are easily blown into the shelf compartments, and do not prevent the continued blowing of the dust from the shelves in the event of a delayed explosion.

Although a set of such shelves can be placed on either side of any kind of a stopping, it was thought that in a dry mine a double set with a 6 to 12 inch space between shelves could be filled with rock dust and made an effective stopping without any containing walls. Such a stopping would offer little resistance to the passage of the explosion, and the blowing of the dust off the shelves would effec-

![Diagram of stopping system]

**Figure 1.**—Plan, elevation, and vertical cross section of rock-dust-protected mine-air stopping.

tively quench any flame that might attempt to pass through. This form of stopping has proved successful in extinguishing flames in each of several trials.

Plate X, B, shows a set of shelves installed in a mine before the curtains had been hung. Plate XI, A, shows the same set after the curtains had been hung.

Plate XI, B, shows the appearance of a rock-dust stopping after an explosion. A 1-foot space between the two sets of shelves was filled with limestone dust. This dust compartment, as anticipated, acted like a solid wall, and the explosion threw down the set of shelves on the side away from the explosion or the side from which
A. ROCK-DUST-PROTECTED STOPPING, AFTER CURTAINS ARE HUNG.

B. VIEW SHOWING EFFECT OF LIGHT EXPLOSION ON ROCK-DUST-PROTECTED STOPPING.
the picture was taken. The set shown was on the near side. The explosion, passing through the spaces between the shelves, blew most of the dust off the shelves. The flame did not pass beyond the stopping, as was demonstrated by nonignition of pure coal dust beyond.

Plate XII, A, shows the appearance of the remains of a rock-dust stopping after a stronger explosion. The pile of dust in the foreground had been piled at the foot of the nearest set of shelves. All the framework except one post has been blown away by the explosion. Except for a small pile in the foreground, the dust appears to have been uniformly scattered along the entry. The flame was effectively quenched by the device.

ROCK-DUST-PROTECTED VENTILATING DOOR.

CONSTRUCTION.

Inasmuch as ventilating doors are usually placed at the entrance to butt and side entries, points at which it is particularly important to have some means to insure limiting the explosion area, it was thought that advantage could be taken of the well-known vulnerability to wreckage of such doors to design a device for producing a thick cloud of rock dust to check any explosion that might start in spite of other protection.

The rock-dust-protected ventilating door consists of a mine door of the usual type, though as small as is expedient without interference with haulage; around the frame of the door, at the sides and overhead, are constructed compartments to be filled with incombustible dust. The compartments are constructed without the use of spikes or bolts in such a manner that the walls and overhead compartment floor are held in position by the door frame. The frame is strongly constructed, and its displacement as a whole by an explosion causes the collapse of the compartments and the consequent projection of the rock-dust contents into the entry. The floor boards of the upper compartments are hung by chains secured to the roof or, in case of poor roof, to roof timbers. The chains allow the boards only a limited fall to different heights, so that the boards delay the fall of some of the dust and also retain some of the load, which is then available to quench a delayed flame or a secondary explosion. This arrangement is primarily intended for a light explosion, which is the most difficult kind to check; as the pressures are low it is necessary to have a device that will be sensitive to a blast of air. An explosion having a strong pressure offers little difficulty, as then the whole framework and the compartments are demolished and the mass of rock dust is launched into the air, quenching the explosion.
Figure 2 shows a plan view of the device, indicating the relation of the side compartments to the door frame, a front elevation of the device, and a vertical section along the line a–b.

As already mentioned, the mine door is made as small as practicable for the mine conditions, so as not to inconvenience haulage operations, and the remaining entry space is utilized for dust compartments. If the roof is low it may be necessary to take down some of it. The excavation should be tapered off gradually in either direction.

**METHOD OF ERECTION.**

Cross bars, 5 (fig. 2), are set near the roof upon posts in grooves in the rib. Beneath them, posts, 6, are set up and firmly wedged or nailed to bars 5. The side planks, 8, of the side dust compartments are then temporarily nailed during construction to the outside of the posts. The door frame is set up between the planks of the two side compartments, the crossbar, 3, being of sufficient length to force or spring in the planks a little, so that they will be held firmly in position when the rock dust presses against them. After the frame is in place the temporary nails in the planks, 8, are withdrawn.

Braces, 14, are placed against the side of the frame on the opposite side to that on which the door will be hung, so that the frame will be enabled to withstand the shocks from the door closing violently with the ordinary mine operations without dislodging the
A. VIEW SHOWING EFFECT OF STRONG EXPLOSION ON ROCK-DUST-PROTECTED STOPPING.

B. ROCK-DUST-PROTECTED VENTILATING DOOR. END BOARD OF UPPER COMPARTMENT HAS BEEN REMOVED TO SHOW CHAINS.
frame. The door is hung by the usual type of hinges, 2, to the door frame in such a way as to be self-closing. The short planks, 7, are set in place on the inside of the posts at the ends of the side compartments; these also are not nailed but are held in position by the dust loading.

Crossbars, 10, are then placed on cleats, 9, attached to the posts, 6. The crossbar on the door side of the frame is preferably placed somewhat higher than the other crossbar, 10, as the free end of a self-closing door needs additional height when open. Short planks, 12, are placed from the crossbar 3 of the door frame to the crossbars 10. End planks, 13, are placed from rib to rib to inclose the ends of the upper compartments.

In testing this arrangement in explosions, as with the concentrated barrier and box barrier, it was found desirable to fasten the floor planks of the upper dust compartment by chains to the roof, allowing them only a limited drop, adjacent boards dropping different distances. The reason for this is, as previously mentioned, that under some circumstances the preliminary air wave may be some distance ahead of the flame, and if the advance air wave or if the shock wave of a violent stage of the explosion farther in the interior of the mine arrives before the flame, which may be delayed, there will be rock dust still remaining on the shelves to quench the flame.

It was also found that the ends of the planks 8 tended to bulge outward when the side compartments were filled with dust. To prevent the spilling of dust through the crack, a 2 by 4 inch scantling was nailed near the ends of the planks 8 to fit just inside of planks 7. When the ends of the planks 8 bulge outward, the scantling prevents the spilling of the dust by making a sliding joint.

If the explosion advances from the side on which the door is hung the door is forced tightly against the frame and even a light pressure over such a large surface will quickly dislodge the frame unless it is well braced to prevent its being too sensitive. If the explosion advances from the opposite side, the door will be apt to blow open, and so not receive the full force of the explosion wave; but as the frame is not braced in that direction, it is dislodged about as easily as from the other direction. It has been found in the tests already made that the frame is dislodged without delay, irrespective from which side the explosion comes. However, it is desirable to make the door frame proper relatively deep and wide to present considerable surface to an explosion to make sure that it will be blown out and thus release the rock-dust compartments as described.

Plate XII, B, shows a rock-dust-protected ventilating door, with the end board of the upper compartment removed to show the chains attached to the bottom boards of the compartment.
RESULTS OF EXPLOSION TESTS.

Plate XIII, A, shows the effects of an explosion on a rock-dust-protected ventilating door in a mine entry. The door frame was blown out entirely and the plank of the side compartments scattered out into the entry. The explosion was sufficiently strong to break some of the chains and pull down some of the roof in which chain hooks were fastened. The wide distribution of the dust is plainly shown. The device successfully stopped the explosion.

Plate XIII, B, also shows the results of a violent explosion on a rock-dust-protected ventilating door. The entire framework of the barrier has been blown away, the only pieces remaining being a few chains hanging from the roof. The dust is scattered uniformly along the entry as far as one can see. In this explosion the flame was effectively quenched by the rock-dust shower.

ROCK-DUST-PROTECTED OVERCAST.

CONSTRUCTION.

In mine explosions, overcasts are almost always disrupted or demolished owing to the large extent of surface on which the explosive force can act. For example, if the pressure of the explosion is only 20 pounds per square inch, a relatively light pressure, the total lifting pressure on the floor of an ordinary 9 by 12 foot overcast would be 130 tons and about 100 tons pressure on either side. As a result of their destruction the explosion frequently passes to other parts of the mine. It was thought, therefore, that advantage could be taken of the vulnerability of the overcasts to produce a dense cloud of rock dust to extinguish an explosion at such points. The rock-dust-protected overcast is designed to give such an effect.

The device consists of an overcast of any type of construction, the floor and sides of which are protected by rock-dust compartments. Figure 3 represents a longitudinal section of an overcast showing the arrangement of dust compartments, A transverse section, and a plan view indicating the arrangement of the device in the mine, as well as certain details of construction are also shown.

METHOD OF ERECTION.

In A, figure 3, 1 indicates a main entry and 2 an airway, which are separated by the overcast. The side walls are made double with a space between them, 2 to 3 feet wide, which is filled with rock dust, the outer sides may be planned like the rock-dust stopping, described above. The walls may be made in any suitable manner, the framing in the diagram showing one method of construction. The framing is preferably made light so that an explosion will readily disrupt the
A. EFFECTS OF EXPLOSION ON ROCK-DUST-PROTECTED VENTILATING DOOR.

B. RESULTS OF A VIOLENT EXPLOSION ON ROCK-DUST-PROTECTED DOOR.
walls and permit the rock dust to be projected into the entries. In like manner the floor of the overcast has a compartment, 4, built above it with angle dust compartments, 9, connecting it with the side compartments. All of the hollow space is filled with rock dust. If the overcast is built in a place where water is dripping from the roof, it is desirable to place some waterproof covering over the top of the dust compartments in order that the dust will not become wet. No piles of "slate" or gob should be permitted to be placed against the side walls of the side compartments, as such piles tend to prevent the most efficient operation of the barrier in the event of an explosion.

If the overcasts used in a given mine have hitherto been of the type in which steel beams are used, or if a solid concrete floor has been employed, it is preferable to modify the construction by making the floor system so that it is less rigidly tied together. An excellent form of construction is to use iron beams with small slabs, bricks, or boards over or between the beams, in order that the overcast shall offer less resistance to the disruptive force of the explosion and thus assist in throwing the rock dust into general suspension to quench the flame. There has not yet been opportunity of testing this type of overcast in an experimental explosion, but in view of the success attending the tests of the other kinds of rock-dust barriers it is thought by the engineers of the bureau that the device will operate successfully.

**ROUGH ROCK-DUST BARRIER.**

Since the foregoing part of this paper was prepared another type of inclosed rock-dust barrier has been designed by engineers of the bureau. This barrier, which has been termed the "rough rock-dust barrier," was tested at the experimental mine and successfully pre-
vented the passage both of strong explosions of coal dust and of feeble ones, and also of an explosion of dust in air which contained a small percentage of inflammable gas.

DESCRIPTION OF BARRIER.

The essential features of the barrier (Pl. XIV) are six fixed troughs placed about 6 feet apart, across the entry and close to the roof, each of which contains longitudinal bars, 1, 2, and 3, or grids which separate the mass of rock dust filling the trough and, in case of the barrier being dumped, break up the mass of dust and cause it to cascade in falling; a drop shelf, 4, which is held up by chains after falling about 6 inches; hinged bottom boards, 5, each of which is held up along one edge by a wood strip, 12, which acts as a hinge, and by supporting levers, 6, and trip levers, 7, operated by strong wires, 8, from advance vanes, 9 and 10. Each trough is supported on the four corners by roller bearings, 11, which rest on side frames, or on studs between posts if the passageway or entry is timbered. Also, if the entry is timbered, each trough may be set in a space between collars. In falling, the bottom boards, after clearing the strip hinges, 12, are caught by loose chains as a safety precaution should the barrier be dumped when some one was passing under it. The troughs extend across the full width of the entry and if it is 9 feet wide the six troughs will hold 2 to 2½ tons of rock dust. On each side of the set of troughs are two advance vanes, 50 and 100 feet from the barrier, which are similar to those employed for the concentrated barrier described in pages 27 to 32. Two tripping wires, one on each side of the entry, are joined at the outer or advance vane to a chain which passes around a pulley and back to the lower edge of the vane; the intermediate vane requires two chains and pulleys, one for each wire. Hooks or staples in the roof, or collars if the entry is timbered, keep the wires from sagging and overhead out of the way. Each wire trips the levers on its side of the entry. The wires from the set of advance vanes “ahead” of the barrier connect to the upper ends of the tripping levers, 7, and those from the advance vanes “behind” the barrier connect to the lower ends of the tripping levers. By means of this arrangement, if a comparatively light explosion pressure reaches the vanes which are ahead, with reference to a point in the entry, the weight of the vanes behind the barrier will not have to be overcome by the wires in pulling the tripping levers, as indicated in Plate XIV, A and B. The terms “ahead” and “behind” are merely explanatory, as the barrier is symmetrical and an explosion approaching from either direction will operate it.

The weight carried on each supporting lever is about 150 pounds, and as the leverage is in the ratio of 2 to 1, the upward pressure on the tripping lever is 75 pounds. The sliding frictional resistance of
A. ELEVATION OF TROUGH BARRIER WITH SIDE FRAME REMOVED, AND END VIEW.

B. LONGITUDINAL ELEVATION OF TROUGH BARRIER.
the catch, by interposing a sheet of brass, will not exceed 15 pounds; and if 1 pound be allowed for the turning friction of the lever, the force required to trip it is about 16 pounds. The tripping wires are fastened to the tripping lever at points twice the distance from the axis, 13, that the catches are, hence the pull required to trip the lever is about 8 pounds. For 6 levers the pull on one wire is about 48 pounds, and for 12 levers, 6 on each wire, it is about 96 pounds. An advance vane has about 8 square feet of exposed surface, and as one edge is hinged, the pressure required to operate the barrier is about 24 pounds per square foot of vane surface. Such a pressure would be given by an air current having a velocity of 70 miles per hour, or about 102 feet per second, as calculated from the Smeaton formula, \( P = 0.005 \, V^2 \), or if one uses the Martin formula, \( P = 0.004 \, V^2 \), by a current with a velocity of 113 feet per second. In either case, the velocity is less than was observed in the lightest explosion in the tests in the experimental mine, and yet far greater than that of any ventilating current. Moreover, the total force of the pull (96 pounds) required would be too great for the barrier to be accidentally tripped by men or boys in passing. The vane is also protected by a plank placed across the entry underneath the vane, but with sufficient clearance for cars and men.

In the event that the vanes should fail, the arrangement of resting the corners of each trough on ball bearings or rollers (which should be made of bronze to prevent corrosion) permits the trough to be pushed laterally by the force of an explosion, causing the bottom rests to slide off the side levers and permitting the bottom to fall and discharge the dust as readily as if the trigger levers had operated. However, to move a trough in this way requires a greater wind pressure than is necessary with a vane; hence for sensitive action the chief reliance is placed on the vanes. In the case of a violent explosion the sensitiveness of the barrier is not a matter of much importance, as then the barrier troughs are completely smashed by the advance wave, and the two tons of rock dust are instantly whirled away in a cloud, cooling and quenching the flame.

A mixture of rock dust and coal dust that contains 75 per cent of rock dust will prevent the propagation of an explosion if \( 3\frac{3}{4} \) pounds of rock dust per linear foot of entry is present. This quantity of rock dust, if all of it is raised into the air, is equivalent to 1 ounce per cubic foot of space. As there is over 4,000 pounds of rock dust in the barrier, if but 30 per cent, or 1,200 pounds, was raised in the air by the advance wave, it would fill the space, at the above rate of 1 ounce per cubic foot, of an average entry (60 square feet in cross section) for a linear distance of 320 feet. The flame of an explosion, after it is well started, judging from the photographic records so far obtained from the experimental mine manometers, has a longi-
tudinal length from fore front of flame to back of 20 to rarely exceeding 100 feet; hence it is believed that the quantity of rock dust provided in the barrier gives a good margin of safety, provided the rock dust is launched into the air sufficiently in advance of the flame, and this condition, it is believed, is well provided for by the advance vanes.

**COMPARISON WITH OTHER BARRIERS.**

In comparison with the box barrier and the concentrated barrier, the trough barrier has the merit that it is more cheaply constructed than the concentrated barrier, though not so compact, and it is thought that it is equally sensitive and efficient, but possibly not so positive in separating divisions of a mine as the concentrated barrier of the solid platform type. The trough barrier does not take so much headroom as the box barrier; it is more sensitive for light explosions, and is better adapted for trolley roads, though it necessitates greater distance for installment on account of the advance vanes. It requires only 14 inches space above necessary headroom, and if an entry is timbered each trough may be placed between timber sets.

**CONCLUDING REMARKS.**

In conclusion, it may be advisable to state again and further to emphasize that, although the stopping devices have been described in detail so they may be easily constructed by mine mechanics, it is not the thought of the designer nor of the joint authors of this publication that these devices will in any way take the place of systematic treatment of the coal dust. Prevention of ignition of either fire damp or coal dust by methods described in previous pages is safer and more certain than attempting to stop an explosion once started. The use of the barriers is comparable with the employment of block signals on a railroad, if other measures fail they come into play and may prevent a great disaster.
PUBLICATIONS ON MINE ACCIDENTS AND METHODS OF COAL MINING.

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Bulletin 48. The selection of explosives used in engineering and mining operations, by Clarence Hall and S. P. Howell. 1913. 50 pp., 3 pls., 7 figs.


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


Bulletin 60. Hydraulic mine filling; its use in the Pennsylvania anthracite fields; a preliminary report, by Charles Enzian. 1913. 77 pp., 3 pls., 12 figs.


Bulletin 69. Coal-mine accidents in the United States and foreign countries, compiled by F. W. Horton. 1913. 102 pp., 3 pls., 40 figs.


TECHNICAL PAPER 17. The effect of stemming on the efficiency of explosives, by W. O. Snelling and Clarence Hall. 1912. 20 pp., 11 figs.

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TECHNICAL PAPER 52. Permissible explosives tested prior to March 1, 1913, by Clarence Hall. 1913. 11 pp.


TECHNICAL PAPER 69. Production of explosives in the United States during the calendar year 1912, compiled by A. H. Fay. 1914. 8 pp.

TECHNICAL PAPER 71. Permissible explosives tested prior to January 1, 1914, by Clarence Hall. 1914. 12 pp.

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

TECHNICAL PAPER 76. Notes on the sampling and analysis of coal, by A. C. Fieldner. 1914. 59 pp., 6 figs.


TECHNICAL PAPER 85. Production of explosives in the United States during the calendar year 1913, compiled by A. H. Fay. 1914. 15 pp.


MINERS' CIRCULAR 7. Use and misuse of explosives in coal mining, by J. J. Rutledge. 1914. 52 pp., 8 figs.


