Bulletin 56

DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

JOSEPH A. HOLMES, DIRECTOR

FIRST SERIES OF COAL-DUST EXPLOSION TESTS IN THE EXPERIMENTAL MINE

BY

GEORGE S. RICE, L. M. JONES, J. K. CLEMENT

AND

W. L. EGY

WASHINGTON
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EXPLOSION ISSUING FROM PORTAL, TEST 15.

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INTRODUCTION.

By George S. Rice.

This report has been prepared, not only for the purpose of recording the results of the first series of coal-dust tests conducted in the experimental mine of the Bureau of Mines, but also to place before the mining public a description of the mine and an account of the objects sought in its establishment.

Soon after the organization of the technologic branch of the United States Geological Survey, J. A. Holmes, then chief of the branch, concluded that for the solution of various problems relating to the causes and prevention of mine explosions it would be best to carry on large-scale tests in a mine rather than in a surface gallery.

The idea of utilizing the underground passage of a mine for making explosion experiments did not at first meet with general approval among investigators in this country or abroad. Many thought a mine passage was not a proper place in which scientific tests could be conducted, as great difficulty in controlling conditions was expected. However, after all arguments for and against such an investigation had been carefully considered, plans for opening an experimental mine were definitely adopted by the Bureau of Mines in 1910, and an allotment of funds was made to carry out the project. The first endeavor was to find an existing mine suitable for the purpose, but the mines offered by owners were either worked out, were wet, had poor roofs, or presented complications of various kinds, so that it was finally decided to open a mine if a site could be obtained having natural conditions that would fill the various requirements.

A most desirable location was found on property of the Pittsburgh Coal Co., near Bruceton, Pa. The president of this company, Mr. W. K. Field, the general manager, Mr. G. W. Schluederberg, and the chief engineer, Mr. E. J. Taylor, rendered every possible service in making arrangements for the lease of the property and subsequently in the opening of the mine.

Immediately on completion of the development of the mine to the extent considered desirable for experimental work, the first series of tests was begun.

The number of experiments embraced in the first series, here reported, was comparatively small. The tests chiefly served to try out the mine and apparatus; apart from this end, there was valuable educational service accomplished by certain tests before large audiences of mining men. The fact that coal dust in air containing no inflammable gas may explode is now almost universally conceded in this country. This was not the case prior to the first public test of October 30, 1911, when many still doubted even after having witnessed explosion tests in the Pittsburgh surface testing gallery. However, as a result of the mine test mentioned, those who had previously doubted expressed themselves as convinced.

This explosion test seriously damaged the mine equipment, necessitating considerable delay before repairs could be completed. Then followed further experiments, which were limited in number by lack of funds.

PHENOMENA OF A DUST EXPLOSION.

When a source of heat, for example, an incandescent platinum wire, an electric arc, or the flame from a blown-out shot, is introduced into a cloud of coal dust, combustion takes place between the particles of dust and the oxygen of the air. If the quantity of heat transferred to the dust cloud is relatively small, the combustion may proceed only in the immediate vicinity of the heating agent. If, on the other hand, sufficient heat is available, the temperature of the dust cloud is raised to such an extent that combustion takes place rapidly, developing more heat than can be conducted away. Consequently the adjacent part of the dust cloud is heated to a temperature sufficient for rapid combustion, and by its combustion develops heat, which in turn raises the temperature of the next dust layer. This process continues, and the flame travels through the dust cloud with rising temperature and increasing velocity.

In this report the term "ignition" is used to describe the propagation of the flame beyond the immediate influence of the igniting agent.

When the conditions are favorable, the flame is propagated through the dust cloud with rapidly increasing velocity and rising pressure. A true dust explosion then results, and the velocity of the flame rises rapidly to over 2,000 feet per second and great pressures are produced.

When an explosive gas mixture is ignited at the closed end of a tube that is open at the opposite end, the flame travels with rapidly increasing velocity toward the open end. In the early stage of the gas explosion the flame is usually propagated in the way just described for a dust explosion; that is, the heat evolved by the combustion in one layer of gas raises the temperature of the adjoining layer above the temperature at which ignition takes place. In certain gas mixtures, for example, a mixture of hydrogen and oxygen, after the flame has traveled a certain distance from the point of ignition an "explosion wave," or so-called "detonating wave," is set up, and from this point the explosion is propagated almost instantaneously.

The term "detonation wave" has been defined by Prof. Harold B. Dixon[a] as follows:

> The expression "l'onde explosive" coined by Berthelot, and its English equivalent, "the explosion wave," signify that flame which passes through a uniform gaseous mixture with a permanent maximum velocity. The rate of the "explosion wave" is a definite physical constant for each mixture; the explosion wave travels with the velocity of sound in the burning gas, which itself is moving rapidly forward en masse in the same direction, so the explosion wave is propagated far more quickly than sound travels in the unburned gas. * * * In the explosion wave, each layer of gas is compressed so suddenly that it is raised beyond its ignition point by the heat of compression. * * * I use the word "detonation" to express the burning taking place in the explosion wave, since a "detonator" when struck burns in this way itself and sets up an explosion wave in explosive gases around it.

As the phenomena of coal-dust explosions are in many respects similar to those of gas explosions, it is not impossible that an "explosion wave" or "detonation wave" may be produced by a dust explosion in a tube or gallery of uniform cross section under certain conditions. A mine heading or entry never presents the uniformity of a tube or an artificial gallery, because in a mine passage there are irregularities due to projections of roof and ribs, to turns, to side openings, to timbering, and to great variation in the amount and quality of dust present. Therefore it does not seem probable that in a mine explosion a detonation wave of permanent maximum velocity can occur, although in some localities the disruptive force of an explosion may be so great that in popular language it might be termed "detonation."

When a coal-dust explosion is caused by a blown-out shot, a pressure wave is started that travels at a rate of a sound wave;[b] this wave, which in this bulletin has been termed the "shock wave," gradually becomes less and less in amplitude as it travels from the origin. Near the originating blast, if several pounds of black powder

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[a] Report of Committee on British Coal Dust Experiments, Record of first series, 1910, p. 150.

[b] Nearly 1,100 feet per second in a mine passage, varying slightly according to the temperature of the air and the velocity of the ventilating current.

or dynamite has been used, the concussion may be strong enough to raise near-by coal dust into suspension and thus expose the dust to ignition from the flame; but the blast concussion alone can probably not raise dust sufficient for propagation of the flame under the conditions present in the experimental mine for more than about 100 feet. Following the shock or shot wave are other pressure waves which are started by the expanding gases from the burning coal dust thrown into the air by the concussion from the shot. The fact must be emphasized that unless the dust is raised into the air in a cloud it can not explode. If the dust cloud is dense and other conditions are favorable for intense combustion there is a correspondingly rapid production of hot expansive gases with resultant high pressure, causing the pressure waves and the flame to attain high velocities.

The pressure waves started by the explosion are transmitted to the air ahead, and doubtless travel through it at the rate of sound waves. The body of air is forced ahead of the explosion, and as the pressure waves travel through this, the total velocity of any one of the almost infinite number of successive pressure waves with reference to a fixed point is therefore greater than that of a sound wave. When the combustion is relatively slow the advance air waves may get considerably ahead of the combustion or exploding zone. On the other hand, if the conditions for propagation are favorable, the distance that the air waves are in advance will lessen proportionately.

The existence of the advance air-pressure waves is an all-important factor in the propagation of a dust explosion, for if there were none, the coal dust would not be brought into suspension in the air and thus furnish fuel for continuance of the combustion; the English have popularly termed the advance pressure wave the "pioneering wave" and the dust cloud "the pioneering cloud."

There is no doubt that a dust explosion will die away, if a dustless zone is reached, just as soon as the coal dust carried forward in suspension and its unburned gases have been consumed. Similarly, coal-dust explosions can be prevented from starting by so wetting the dust that it can not be raised into the air by concussion. A dustless condition would be equally good, but can hardly be attained in the average mine.

The French (Liévin) experiments indicate that the maximum pressure is exerted in the zone of combustion. This fact is determined from the automatic photographing of the flame itself on the same revolving film as that on which the pressure curve is photographed. The pressure curve is obtained through the agency of a ray of light reflected from a mirror attached to the back of a diaphragm which is exposed to and is deflected by the pressure. The pressure curve indicates that the greatest pressure of the explosion is exerted in the zone of combustion. This maximum pressure wave may be termed the "main pressure wave." The records of the European experiments have shown that as the main pressure wave travels ahead it throws off reflex pressure waves that travel back toward the origin, and that if the origin is at the closed end of the gallery, the pressure may be raised above what it was at the time of ignition.

Following the passage of the pressure waves there is a depression below atmospheric pressure, which is caused by the cooling of the gaseous products of the explosion and by the ejectment of the gases by the violence of the explosion. The depression causes a violent movement or inrush of air from other parts of the mine, or from the outside, to fill the partial vacuum.

The pressure waves and their movement are very complex even in a single gallery closed at one end, but become more complicated in a mine with two or more passageways. Taffanel, in reports [a] on his third and fourth series of coal-dust experiments conducted at Liévin in a single main passageway 300 meters (1,000 feet) long, has contributed most important information relative to waves developed in a gallery by simple explosions of dust and the arresting of the explosions in various ways.

OBJECTS OF DUST-EXPLOSION INVESTIGATIONS.

A thorough knowledge of the nature of coal-dust explosions, and of the accompanying phenomena, is necessary in order to devise means for the prevention of such explosions, and for the arrest, or rather, the stoppage of explosions if by mischance explosions start. It is therefore necessary to know how coal dust ignites and the various means by which it may be ignited, or inflamed, the chemical processes that take place, the circumstances under which an inflammation becomes a true explosion, and whether detonation sometimes takes place.

In endeavoring to discover the natural laws underlying ignitions and explosions, the bureau considers the factors or variables mentioned below. Some of these are properly subjects for laboratory investigations, and the others for investigations at the experimental mine. The laboratory investigations of several, in particular those relating to the relative inflammability of the different dusts, have been pursued in the laboratories of the bureau at Pittsburgh and in other laboratories, especially in England and France.

[a] Taffanel, J., Troisème série d'essais sur les inflammations de poussières; production des coups de poussières, April, 1910; Quatrieme série; theorie des explosions, August, 1911.

INFLAMMABILITY FACTORS PROPERLY INCLUDED IN LABORATORY STUDIES.

Factors affecting inflammability that are properly included in laboratory investigations are as follows:

(1) The chemical composition of typical coal dusts.

(2) The relative inflammability of dusts containing different percentages of volatile matter, ash, sulphur, and moisture, as tested by different laboratory methods and apparatus and as influenced by:

(*a*) Character of ignition coil, induction spark, electric arc, or flame.

(*b*) Size of coal-dust particles.

(*c*) Method of putting coal dust into suspension.

(*d*) Method of mixture with inert dusts and chemically unstable compounds to give extinguishing effects.

(*e*) Presence of methane and other gases.

(*f*) Size and shape of explosion chamber.

(3) The physical nature, composition, and affinity for oxygen of each of the component substances that make up the coals from which inflammable dusts are derived (microscopic and chemical investigation).

(4) The nature and composition of gases distilled from the coal dusts at different temperatures and during different periods of exposure to heat.

FACTORS PARTLY UNDER CONTROL IN EXPERIMENTAL EXPLOSIONS IN THE MINE.

Factors more or less under control in experimental dust explosions in the mine are enumerated below. The bureau is investigating the effect of each in connection with its study of dust explosions.

(1) Source, composition, and relative inflammability of dust.

(2) Size and character of dust particles.

(3) Admixture of inflammable dust with inert dusts.

(4) Quantity of dust per linear or cubic foot of space.

(5) Method of loading dust—on shelves, on floor, etc.

(6) Moisture adhering to dust and not part of its normal composition.

(7) Moisture on walls, roof, or floor, and not in contact with dust.

(8) Humidity and temperature of air.

(9) Air movement in passageways—velocity and direction with reference to proposed explosion path.

(10) Character of walls, roof, and timbering.

(11) Turns and curves in path of proposed explosion.

(12) Proposed branching of the explosion into other entries by prearranged loading.

(13) Coming together of two explosions by prearranged loading.

(14) Local widening of explosion passage.

(15) Number of side openings, such as cut-throughs, not dust laden.

(16) Dustless zones of various lengths in path of explosion.

(17) Watered zones of various lengths in path of explosion.

(18) Stone-dust zones of various lengths and kinds in path of explosion.

(19) Means of ignition of coal dust, such as:

(*a*) Blown-out shots of various intensities with various explosives.

(*b*) Explosion of fire damp.

(*c*) Electric arcs or glowing wires or blowing out of fuse.

(*d*) Open flame when dust is already in suspension in air.

(20) Length of mine passage used in test.

(21) Character of mine passage—double or single or closed at one end, that is, "in the solid."

VARIABLE EXPLOSION CHARACTERISTICS FOR DETERMINATION IN EACH TEST.

Variable explosion characteristics subject to determination in each test are as follows:

(1) Velocity of flame at different stages of explosion.

(2) Velocity of pressure waves at different stages of explosion.

(3) Relative position of flame and of pressure waves.

(4) Rise and fall of pressure, above and below the atmospheric, at different points in the course of an explosion.

(5) Composition of gases at various stages of an explosion, the samples being gathered automatically.

(6) Temperature of explosion at different stages, as determined by thermocouples, or by strips of metal of different melting points.

(7) Composition of coke and ash residues from explosion, and their position with reference to direction of explosion.

(8) Manifestations of violence.

PROBLEMS TO BE INVESTIGATED AFTER DETERMINATION OF STATED VARIABLES.

Below are enumerated problems that the bureau will investigate after having determined satisfactorily the influence of the variables mentioned above:

(1) Length of dust-laden zone (of given cross section) measured from a blown-out shot (of certain strength) that, through the ignition of its dust, creates sufficient pressure waves to raise dust beyond, and thus permit propagation of the explosion beyond the influence of the blown-out shot.

(2) Length of a dust cloud, which, when ignited by an arc or open flame, will cause pressure waves to stir up the dust beyond and cause a propagation of the ignition or inflammation.

(3) The circumstances under which the ignition or inflammation becomes a strong explosion, productive of violence.

(4) Possibility of producing a coal-dust "explosion wave" or "detonating wave" of permanent maximum velocity.

(5) The presence, origin, and character of reflex waves thrown off from the main explosion pressure waves and traveling back toward the point of ignition.

(6) Chemical reactions taking place at different stages of an explosion.

OUTLOOK FOR SOLUTION OF COAL-DUST PROBLEMS.

The solution of all the problems connected with coal-dust explosions, as outlined above, will not be simple, but with the systematic prosecution of the investigations it is probable that the determinations will be sufficiently complete to enable satisfactory planning of adequate means of preventing explosions and the development of valuable secondary safeguards.

Meantime testing stations in France, England, Belgium, Germany, and Austria are prosecuting similar investigations, and through friendly interchange of information it is expected that the advance will be more rapid than would be made by the bureau's investigators alone.

OUTLINE OF VARIOUS TESTS MADE IN THE EXPERIMENTAL MINE.

In addition to the explosion experiments described in this report, a considerable number of tests was conducted in the exterior gallery to determine the conditions under which ignition of coal dust by an electric arc could be obtained. Subsequently, while the mine headings were being extended, tests were made to determine the relative efficiency in blasting coal of different kinds of permissible explosives, also of black powder, under the natural conditions offered by the mine. With a view to determining the vitiation of mine atmosphere by the use of these explosives, samples of their gaseous products were obtained and analyzed. Some experiments with the treatment of coal dust by calcium chloride for prevention of ignition were made. An important series of tests of two types of gosoline locomotives was conducted with a view to testing mechanical control, and to determining to what extent the exhaust vitiated the mine atmosphere under different conditions of use and of engine adjustment. To repeat, then, although only a small number of large coal-dust explosion tests was made, the mine was constantly used for experiments.

In making explosion tests, one of the most important advantages connected with the experimental mine as compared with a surface gallery is the possibility of experimenting on coal-dust ignition when small quantities of methane are present without the large wreckage that would be liable to result in a surface gallery. The study of the effect of the presence of small quantities of methane is of great importance; probably more often than has been suspected, methane has been present in an amount too small to be detected by a safety lamp yet has been influential in the first ignition and propagation of a dust explosion.

Among other possibilities offered by the experimental mine when equipment suitable for each class of experiments has been installed is that of testing the relative dust production of different kinds of undercutting machines, and of investigating the safety features of underground electrical installations, including tests of devices for greater safety in the use of the electric-trolley locomotive, and of studying problems of mine ventilation, such as the efficiency of fans, doors, and stoppings, and the determination of the frictional resistance to the passage of air currents offered by the ribs, roof, and timbering of mine entries and rooms. The figures currently used as coefficients of friction of air passing through underground passageways are approximations, and the wide range of values of the coefficients given by different authorities shows the need of more positive determinations. Altogether, the possibilities for usefulness of the experimental mine are limited only by the appropriations that may be available from year to year.

The scientific study of coal-dust explosions in the experimental mine has been only begun. The most important results of the preliminary series of experiments described in these pages have been: (1) To convince the mining public that coal-dust explosions can be produced at will in a mine as well as in a gallery, and (2) to show that relatively violent explosions of coal dust can be produced by a violent means of ignition in a comparatively short length of passageway. The second result is of importance because it shows the necessity of preventing an ignition of coal dust rather than of attempting to limit an explosion by zonal treatment except as the latter is made a secondary safeguard.

ACKNOWLEDGMENTS.

For assistance rendered in developing the experimental mine the writer of this introduction, who was placed in general charge of the investigations, desires to express appreciation of the inspiration and guidance received from Director Holmes, and the hearty and efficient cooperation of his associates, L. M. Jones, mining engineer; H. C. Howarth, mine foreman; J. K. Clement, physicist; and W. L. Egy, assistant physicist. Many others connected with the bureau, but not directly connected with the experimental-mine work, contributed valuable assistance, among whom are H. H. Clark, electrical engineer;

J. C. W. Frazer, chemist; J. W. Paul, mining engineer; J. J. Rutledge, mining engineer; H. I. Smith, assistant mining engineer; Clarence Hall, explosives engineer; and O. P. Hood, chief mechanical engineer.

The driving of the mine headings or entries, their lining with concrete, the outside and inside construction of the mine, and the preparation of the mine for each test were under the immediate charge of L. M. Jones, mining engineer, and H. C. Howarth, mine foreman.

The setting up of the instruments, their wiring, their operation, and the interpretation of their records were in charge of J. K. Clement, physicist, and W. L. Egy, assistant physicist.

The analyses of coal, coal dust, shale, and rock dust were made by A. C. Fieldner, chemist; and the analyses of mine atmospheres and mine gases were made by G. A. Burrell, chemist.

DESCRIPTION OF MINE AND EQUIPMENT.

There was no precedent to follow in developing an experimental mine of the magnitude desired. At Segengottes, Austria, in the Rossitz coal-mining district, there is an underground testing gallery, the main passage of which was an abandoned drainage tunnel lined with stone throughout. It is 293.7 meters (964 feet) long, but it is narrow, being only 1.3 to 1.44 meters ($4\frac{1}{4}$ to $4\frac{2}{3}$ feet) wide, and the outer end terminates in a group of houses. Tests of the inflammability of coal dust are carried on in the inner portion of the gallery, but owing to the surrounding conditions large-scale, violent tests are not attempted. Birmingham University, England, has for the instruction of mining students in the use of breathing apparatus and lamps some underground passages in an old mine, but these are not used for explosion tests. Henry Hall, an inspector of mines in Great Britain, experimented with coal dust in 1876 in an adit that was 135 feet long; subsequently, in 1890 to 1893, he conducted series of coal-dust explosion tests in disused shafts about 200 yards in depth.

The many surface galleries erected in the past for experimenting with coal dust are described in Bulletin 20 of the Bureau of Mines.[a]

SELECTION OF A MINE.

The requirements considered by the bureau in planning for an experimental mine were:

(1) The mine should be in a coal bed that produced dust of inflammable character and the other conditions of which favored the possibility of dust explosions.

(2) The mine should be naturally dry and preferably self-draining so as to allow experiments with dry coal.

(3) The main openings of the mine should be drifts, so that complications from possible wreckage of a shaft would be avoided, thus keeping down the expense and permitting a quick entrance to the mine after explosions.

(4) The mine should be as free as possible from methane; that is, the mine atmosphere should contain less than 0.1 per cent, in order that experiments might be made in an atmosphere practically free from inflammable gas.

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[a] The explosibility of coal dust, by G. S. Rice, with chapters by J. C. W. Frazer, Axel Larsen, Frank Haas, and Carl Scholz. 1911. 204 pp. Revision of U. S. Geological Survey Bull. 425.

(5) A natural-gas pipe line should pass near enough to the mine to make feasible the laying of a branch line that would furnish a supply of gas (methane and ethane) for experiments in combination with coal dust and air in varying proportions, or with mixtures of gas and air only.

(6) A good water supply should be available both for boiler use and for fire protection as well as for experiments.

(7) The location should be accessible to a railroad so that the coal produced could be loaded on railroad cars, yet should be so isolated from houses or other buildings that violent explosions would not endanger them.

After much search these requirements were all met by a site near Bruceton, Pa., 13 miles southwest of Pittsburgh, on the Baltimore & Ohio R. R. Here, the well-known Pittsburgh coal bed outcrops along the sides of the valley of Lick Run. In a side ravine, in which there is a small stream, a place in the outcrop was found sufficiently

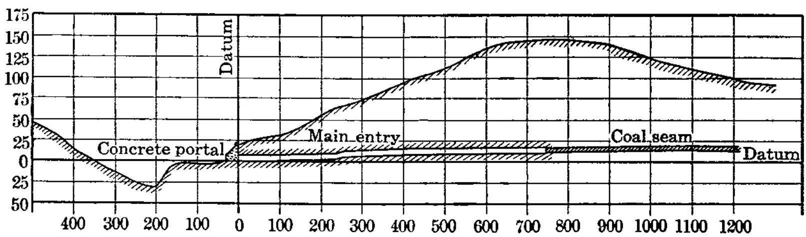

FIGURE 1.—Profile of main entry of experimental mine.

back from the main frontage to allow entrance into the middle of an extensive area of the coal. At the place selected for the drift openings the bed dips gently to the north, and as the opening entries are driven to the southwest they are self-draining. Many samples of mine air have been taken and no appreciable amount of methane has been found; even after the mine has been sealed for 14 hours a maximum of only 0.06 per cent was found at the face of a heading. The drift openings are high enough above the ravine bottom to provide space for a convenient refuse dump and for other features connected with the development of a mine. The hillside above the outcrop rises steeply, so that there is a good cover over the main headings. The crest of the hill is 132 feet vertically above the mine (fig. 1). Across the ravine in front of the mine openings there is a hillside that provides a natural barrier for catching material thrown out by a violent explosion and deflects the air waves upward, a protective feature of great importance in a populated district.

UNDERGROUND DEVELOPMENT.

Drift openings were started in December, 1910, and entries were driven into the coal bed. Drifting proceeded intermittently up to October, 1911, when the first series of coal-dust tests was begun. The underground passages then consisted of two main parallel entries a little more than 700 feet long, each 9 feet wide, with a 41-foot pillar of coal between them. There are crosscuts or "cut-throughs"[a] between the entries every 200 feet. A diagonal heading 198 feet long connects the air course with a third opening (fig. 2); it enters the air course at an angle of 55° at a point 117 feet from the mouth of the air course. Fifty-five feet from the mouth of the air course there is a fourth opening, an air shaft that is offset 6 feet from the entry. This shaft is intended for ventilating purposes only, while the mine is being developed, or as an auxiliary opening in case an experimental explosion should wreck the other openings. The diagonal heading was made in order to provide an opening for ventilation purposes; it was turned off from the main air course, with the expectation that the chief force of an explosion wave would pass directly out of the air course.

The main entries were driven in the coal bed "on the faces," that is, at right angles to the principal vertical cleavage. These entries are of the usual width employed in working the Pittsburgh bed, nominally 9 feet, but ranging between 9 and 9½ feet. It was first intended to place the cut-throughs 100 feet apart, but owing to the expense of constructing tight stoppings strong enough to resist explosions, the distance was changed to 200 feet. In driving the entries, line brattices are carried from the last cut-through up to the face of each entry. Fortunately the natural roof inby the concrete lining is sufficiently strong so that only a few cross timbers have as yet been necessary. Side posts have been put in, not to support the roof but for attachment of the side shelves on which to lay coal dust. In the first two tests these posts were exposed, and hence were blown down; subsequently they were recessed (Pl. II, *A*) into the coal rib, so as not to be exposed to the violence of the explosion. Ordinary mine tracks of 42-inch gage are laid in each entry for handling coal cars and for use in making tests of gasoline and electric locomotives.

REINFORCED CONCRETE LINING.

The main entry is provided with an arched portal of heavily reinforced concrete (Pl. II, *B*, and figs. 3 and 4) with retaining wall, wing walls, and buttresses built "en masse;" the walls are carried down to the solid formation, and the buttresses to a limestone 3½ feet below the coal.

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[a] This term is employed in the bituminous coal mining laws of Pennsylvania of 1911.

The reinforcement consists of ½-inch, ¾-inch, and 1-inch round rods of mild steel placed vertically, diagonally, and horizontally. The vertical rods are set in drill holes in the limestone. The stresses

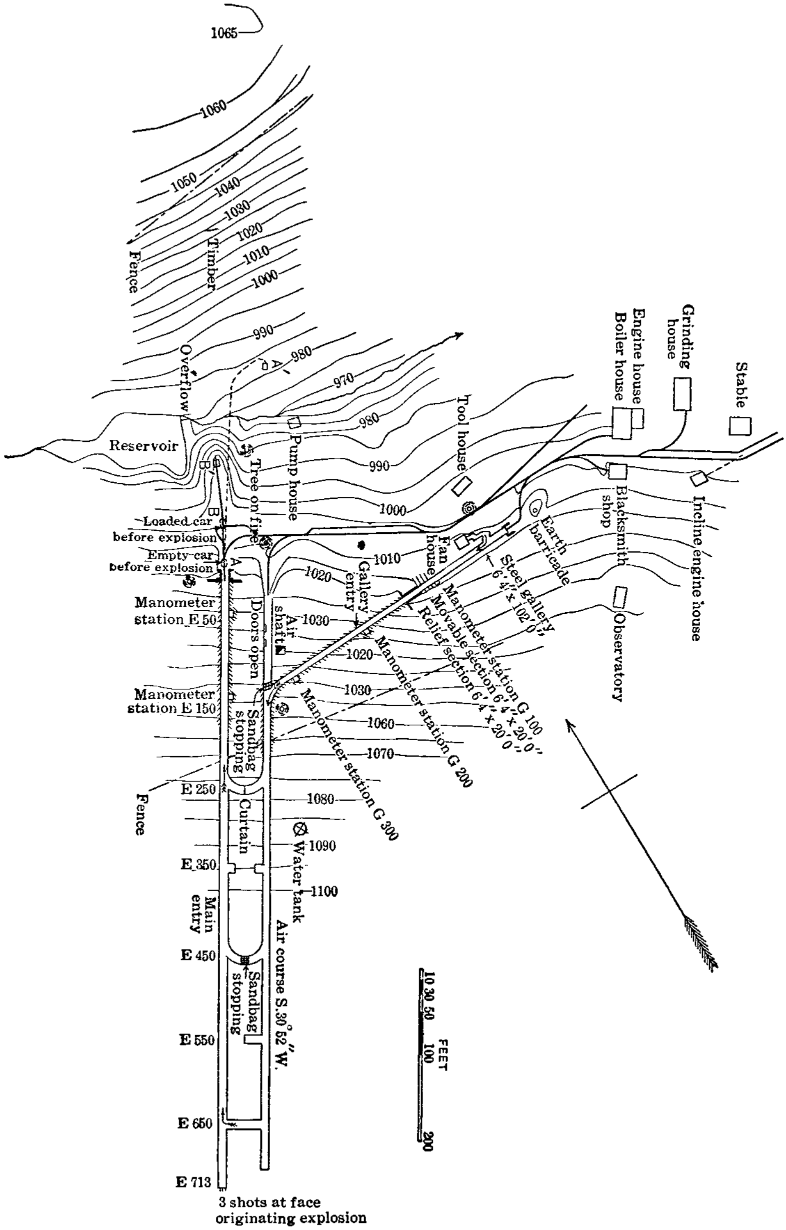
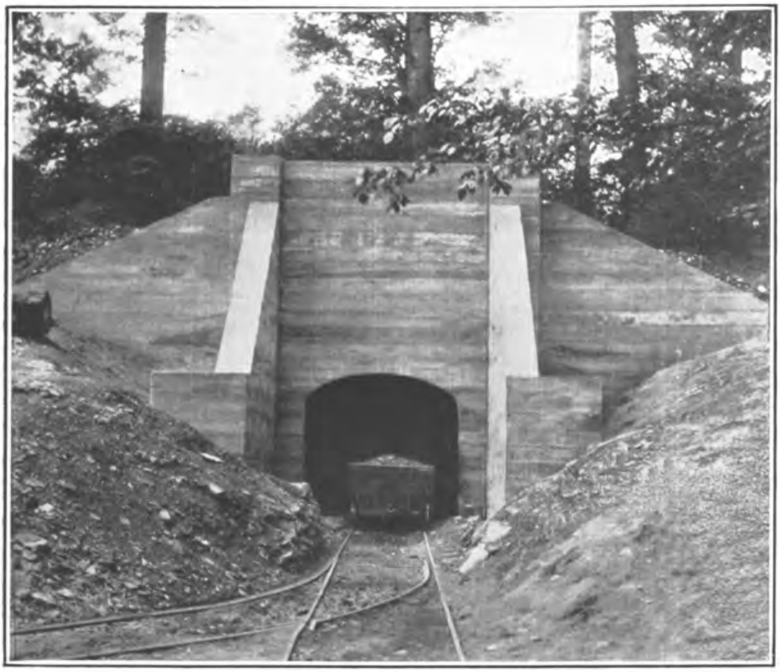


FIGURE 2.—Plan of experimental mine, also surface contours, at time of explosion of October 30, 1911, showing path of mine car thrown by explosion.

considered were (1) those due to forces directed outward from the mine, and (2) a bursting pressure acting at right angles to the axis of the entry or tunnel. The wing walls were also designed as retaining

A. DUST SHELVES IN MAIN ENTRY.



B. FINISHED PORTAL.

walls for the roof shale and dirt cover over the arching of the tunnel. Some of the reinforcement at one stage of construction is shown in Plate III, *A*. The arrangement at the entrance provides for the future addition of a counterweighted door, sliding vertically in grooves, for use in special experiments requiring a perfectly quiet atmosphere.

It was intended that a similar entrance should be placed at the mouth of the air course. Owing to the lack of funds this was not completed for the tests of the first series, but has since been erected. The air-course entrance was not intended to be used for explosion tests during the first series. A reinforced-concrete portal is provided for the

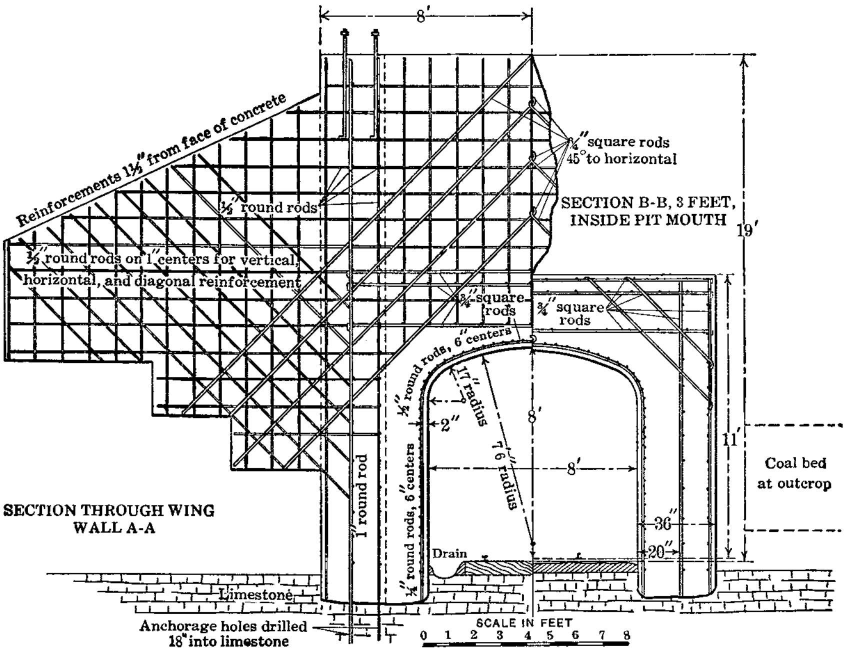


FIGURE 3.—Cross section of reinforced-concrete portal of experimental mine.

diagonal heading similar to that of the main entrance except that the walls are not so heavy, the heading being smaller in cross section.

It was necessary to line the outer parts of the entries on account of the poor roof; indeed this had to be supported by heavy timber while the entries were being driven. It was manifest that timber for lining would not be satisfactory in explosion tests, as the timber would be likely to be blown out. As the best material for lining seemed to be reinforced concrete, a type of lining was adopted similar to that so extensively used in the Béthune mines, Pas de Calais district, France, as designed by J. Lombois, principal engineer.[a] The con-

[a] Lombois, J., Revetement en béton armé des bouvettes et des bures aux mines de Béthune: Bull. Soc. Ind. Min., ser. 4, vol. 6, 1907, pp. 195–205.

crete on the side walls is 7 to 9 inches thick, and thicker in places where irregularities in the natural walls required the filling. The arch is made 7 inches or more thick. As it was necessary to have

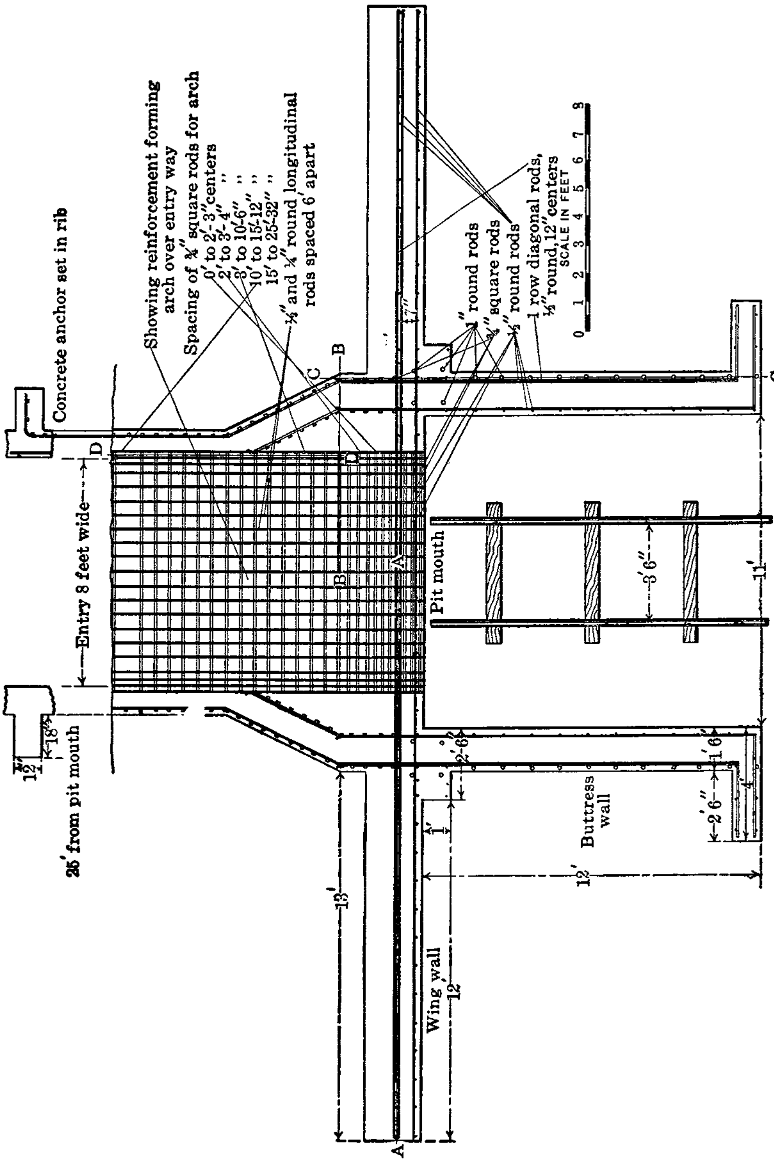
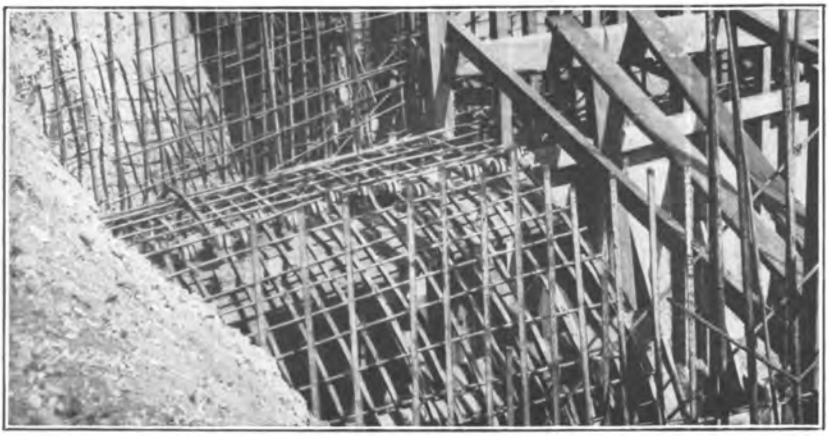


FIGURE 4.—Plan of reinforced-concrete portal of experimental mine.

the lining strong, the concrete mixture was made relatively rich, being 1 part Portland cement to 2 parts sand and 4 parts gravel.

The reinforcing bars of the arch are $\frac{3}{4}$-inch square steel rods, placed 6 inches apart in that part of the entry close to the mouth and 32



A. REINFORCEMENT OF PORTAL.

B. OBSERVATORY AND OTHER BUILDINGS.

C. EXTERNAL EXPLOSION GALLERY.

inches apart farther in. The arches were made in two halves, each half extending from the foundation to the center of the crown, where they were joined together by a bolt passing through a loop in the end of

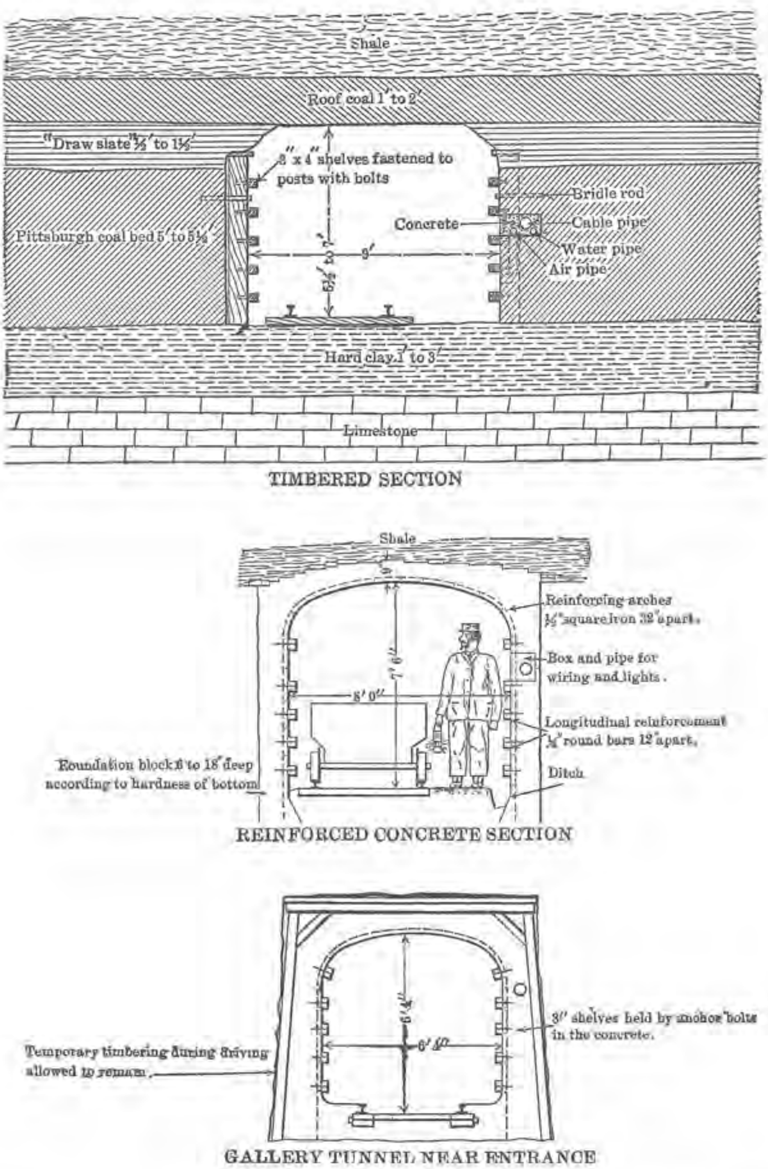


FIGURE 5.—Cross-sectional views of mine gallery.

each half arch. The horizontal reinforcement consists of ¼-inch rods placed 12 inches apart (see fig. 5) and wired to the arch rods at the intersections. The concrete lining was put in place over forms of collapsible type which could be moved from point to point as the work advanced. These forms were similar to those designed by Lombois.[a]

While the concreting material of the lining was being placed, bolts were inserted for the support of five shelves on each side to be used in coal-dust explosion experiments. There was also laid behind the wall a 4-inch steel pipe in which were placed electrical cables, a 2-inch pipe for a compressed-air line, and a 2-inch water main with hydrant boxes every 100 feet. The arched lining, which is finished smooth, is 8 feet wide in the clear, and 7 feet 6 inches high from the top of the track ties to the arch; near the entrance the roof has a slight rise and the floor descends, so that the arch is 8 feet high at the portal. The diagonal heading or gallery is smaller, being 6 feet 4 inches wide and 6 feet 4 inches high (fig. 5).

In constructing the lining in the outer part of the main entry and in the diagonal heading or gallery, the preliminary timbering had to be left in place above the arching as the roof was too weak to allow its removal. Adjacent to the portals the arches were constructed in the open; they were afterwards covered with dirt, which was filled in to the top of the retaining walls. During the first series of experiments the concreting was extended into the main entry, making its total length 169 feet; the entire diagonal heading, 198 feet long, was lined, and in the air course there was a lining from a point 20 feet outby the connection with the diagonal heading or gallery to a point 65 feet inby the junction. At the wide space at the junction the roof had been supported with railroad rails which were left in to supplement the strength of the reinforced lining.

THE PITTSBURGH COAL BED.

The Pittsburgh bed, in quality, extent, and uniformity, is one of the most remarkable coal beds in the United States, if not in the world. It extends southwestward from the vicinity of the city of Pittsburgh to the middle of West Virginia, where there are scattered areas in the hilltops, a distance of about 125 miles; on the west it extends into Ohio; the width is 75 to 100 miles, but not all of this area is underlain with the Pittsburgh bed, as in places the coal is cut out in the valleys of the larger streams and on some of the anticlines that separate the several basins. Although varying in different basins, in any one basin the coal is remarkably regular in quality and thickness. In certain areas the bed produces the highest grade

[a] Lombois, J., Revetement en béton armé des bouvettes et des bures aux mines de Béthune: Bull. Soc. Ind. Min., ser. 4, vol. 6, 1907, pp. 195-205. The reinforcement was placed in the concrete arch to help support the roof. It was thought that the weight of the roof, together with its resistance to shear, could be overcome by the upward pressure of an explosion. This proved not to be true; the arch and roof lifted, causing the arch rods to break through the facing (see Pl. VIII, *C*). In future construction the arch reinforcement will be placed farther from the face of the concrete, and the arch thickened to resist the force of an explosion.

of coking coal, the coal from the Connellsville district making the standard coke of the country; in other basins or districts the bed produces gas and steam coals. The thickness ranges from 5 to 10 feet, but in any one basin the thickness varies little.

At the experimental mine, which is in the so-called "gas-coal" district, the bed is 5 to 6 feet thick, averaging about 5½ feet. Above the coal there is a layer of soft shale ("draw slate") a few inches to 2 feet in thickness, averaging about 1½ feet. This "draw slate" falls or is pulled down with the pick as soon as the coal has been removed. In some places it has to be brought down by light shots. Above the "draw slate" there is a "top coal" or roof coal 1 to 2 feet thick; it in most places is shaly, and in the district in which the experimental mine is located it is not sufficiently pure to be regularly taken down and used for fuel purposes. This top coal, when not broken by blasting, makes a good roof, except near the outcrop. The main roof above the top coal consists of shales of little strength; in some places, but not in the vicinity of the experimental mine, the Pittsburgh bed is overlain with a strong sandstone. The floor is clay, which is hard when first mined, but subsequently air-slacks. At the mouth of the experimental mine the clay is 2 to 3 feet thick and is underlain with a limestone stratum.

The coal bed proper at the experimental mine is free from continuous partings except for two thin bands of shale about 3 inches apart, a little below the middle of the bed. The upper band is one-eighth to three-fourths of an inch thick and the lower three-fourths to one and one-fourth inches thick. The "faces" or "butts" of the coal (Pl. IV, *A*) are strongly marked throughout the whole Pittsburgh coal bed and are of great importance in mining. The coal itself is fairly hard, but owing to the planes of cleavage it tends to break to cubical pieces (Pl. IV, *B*) in blasting and in subsequent handling. The regular method of mining in the Pittsburgh district consists of undercutting the coal either by hand or with machines, generally the latter, and then blasting down with two shots in entry work, or two to three shots in the rooms. In general, through the gas and steam coal districts about one-third of the coal produced is nut coal or finer, and two-thirds is "lump."

The average proximate analysis of coal from the Pittsburgh bed from face-section samples gathered in the experimental mine is as follows:

Moisture	2.7
Volatile matter	36.0
Fixed carbon	55.0
Ash	6.3
	100.0

The average ultimate analysis is as follows:

Hydrogen	5.38
Carbon	76.16
Nitrogen	1.53
Oxygen	9.23
Sulphur	1.40
Ash	6.30
	100.0

SURFACE EQUIPMENT OF THE MINE.

The surface equipment of the experimental mine consists of an external explosion gallery, ventilating fans, a power plant, a coal-dust and rock-dust crushing and grinding plant, an observatory and control station in which recording instruments are placed, an incline, a coal tipple and chute for loading railroad cars, a reservoir, pump house, blacksmith shop, barn, tool house, and a water-tank and hydrant system for fire protection.

EXTERNAL EXPLOSION GALLERY.

The explosion gallery (Pl. III, *C*) consists of a steel tube 6 feet 4 inches in internal diameter and 122 feet long, set in line with the diagonal heading, or "gallery slant," and 20 feet from its mouth. Between the tube and the mine portal there is a U-shaped passage (fig. 6) of heavily reinforced concrete; it has the same diameter (6 feet 4 inches) as the steel tube and the diagonal heading. The roof of this passage is closed by flat plates resting loosely on 2½-inch round tie rods (connecting the tops of the concrete walls) and when necessary is weighted down with sandbags. This loose covering is 20 feet long by 6 feet 4 inches wide and serves as a great relief valve for the protection of the tube and ventilating fan in case of a very violent explosion in the mine.

In order to make the external steel gallery available for small explosion experiments outside the mine itself, the inner 20-foot section, adjacent to the U-shaped passage, can be rolled to one side; then, after the mouth of the diagonal heading has been closed, the steel gallery is isolated from the mine and tests can be conducted in it without interfering with work in the mine. During such periods mine ventilation is carried on by means of a fan set at the top of the air shaft. The steel gallery when thus isolated is 102 feet long and has practically the same dimensions as the gallery for testing explosives at the Pittsburgh station. There is, however, one difference. The outer end of the steel gallery at the mine is left open except for a board or plank stopping which can be slid into place in the concrete framework. This stopping is to provide for relief of violent pressure and therefore is made comparatively thin (of 2 to 4 inch

A. UNDERCUTTING A BREAK-THROUGH.

B. COAL BROUGHT DOWN BY SHOT

Note characteristic cleavage.

plank) in order that it may break and thus lessen the strain on the tube. Twenty-five feet from the outer end of the gallery there is a branch (fig. 2) 6 feet 4 inches in diameter, set at an angle of 60°. This branch is for connection to a fan for use in producing a venti-

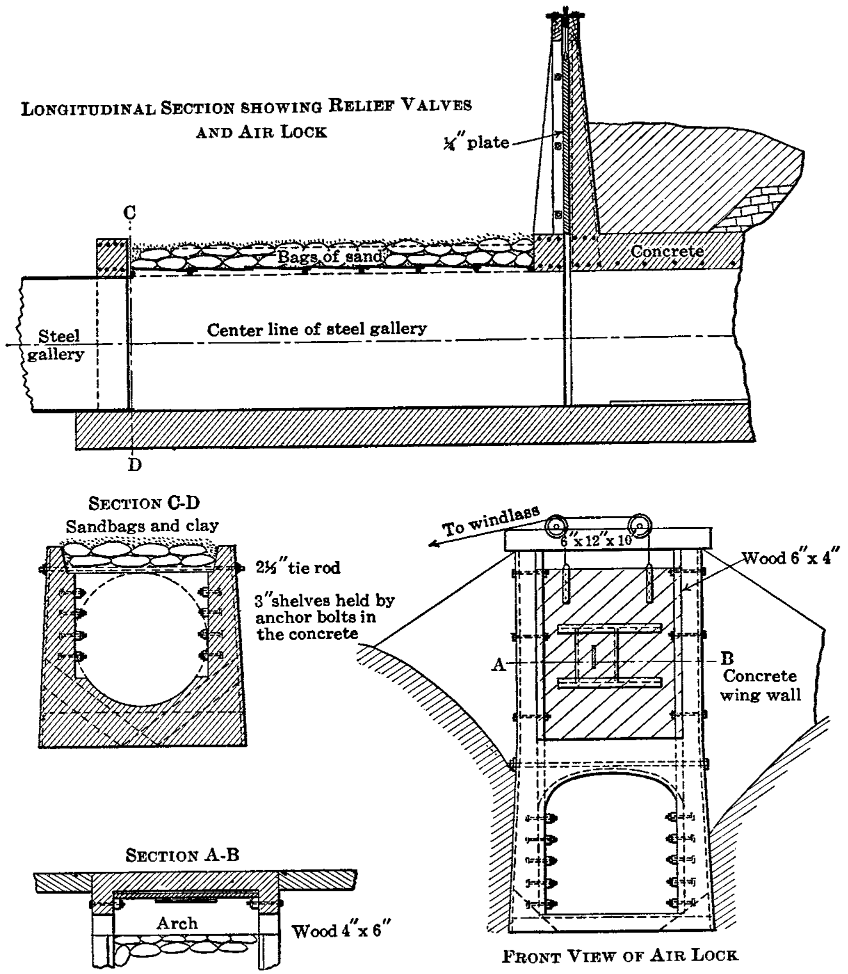


FIGURE 6.—Sections of passage between steel gallery and diagonal entry.

lating current either at the time of an explosion or in the ordinary mine operations.

CANNON FOR IGNITION SHOTS.

For testing explosives or for coal-dust ignition a special cannon similar to those used at the Pittsburgh station is employed. The cannon has a bore hole 2¼ inches in diameter and 18 inches deep; it is mounted on a truck which can be wheeled to the outer end of the steel tube, so that the cannon can point into it through a hole in a heavy plank stopping. The truck has the same gage as the mine tracks, so the cannon can also be used in the mine for making a test in which the equivalent of a blown-out shot is desired. Although long-flame explosives like black powder or dynamite, when used in coal-face shots and so prepared that they will blow out, will readily ignite bituminous coal dust of sufficient purity and quantity, it was found best for experimental purposes to start experimental explosions by means of a blown-out shot from the cannon in order to obtain uniform initial pressures. Another advantage gained by the use of the cannon is that coal-dust explosions can be originated at any predetermined point along an entry or heading of the mine, thus giving conditions similar to those that may occur when a "brushing" shot is fired in an entry or airway.

VENTILATING SYSTEM.

It is intended to have the ventilation at the mine such that it will be possible to duplicate almost any condition liable to occur in an ordinary mine. The entries are double, thus allowing a regular coursing of the air. In future some stub entries will be driven to permit experimenting in a stagnant atmosphere.

The fan, which is now (March, 1912) on hand but not yet installed, is a centrifugal fan of standard make. It is designed for a capacity of 80,000 cubic feet of air per minute at a pressure of 2 inches water gage, or 15,000 cubic feet of air per minute at a pressure of 6 inches water gage. It will be driven by a 100-horsepower steam engine; a belt connection, instead of direct connection, will be used, as the former provides greater flexibility in case of a serious concussion or a sudden stoppage of the fan through violence. The fan is reversible and will be mounted at the end of the branch of the external steel gallery. There will be several relief doors in addition to the protection afforded the fan by its being set to one side of the gallery. Unlike the practice at foreign testing galleries, at which the fan is cut out by valve arrangements a few moments before an explosion is started, it is proposed to run this fan during an explosion in order to parallel conditions that occur in mine disasters.

Unfortunately, sufficient funds were not available for erecting the large fan before the first series of explosion tests, so that a small fan was temporarily set up in place of the large one. The small fan has a capacity of 5,000 to 10,000 cubic feet of air per minute at pressures of 1-inch and ½-inch water gage and is run by a gas engine. It was originally placed near the top of the air shaft and connected therewith for the ventilation of the mine under ordinary conditions, as in entry driving. It was removed from the air shaft and connected with the tube during the first series of tests. It will be returned to the air shaft when the larger fan has been erected.

There has been much contention among mining men as to the effect of a ventilating current on the initiation and propagation of a dust explosion. Some claim that a dust explosion always "goes against the air"; that is, advances toward the intake air on account of the additional oxygen it meets in an opposing current of fresh air. They claim further that this condition has most effect in wintertime when the intake air is colder than the return air and hence has greater density and contains more oxygen per cubic foot. Others have thought that the reason that coal-dust explosions are more apt to traverse the intakes than the returns is that the intake air, cold and carrying little moisture, dries the coal dust, whereas the return air is, as a rule, nearly saturated, and the coal dust in the return passageways is apt to be damp. Many have believed that it was a case of the explosion seeking the dry coal dust, whether this is to be found on intake or return. Further, some have suggested that a high velocity of the air current greatly increases both the risk of a dust explosion and its violence. By conducting identical tests except for the direction of the air current, one set of tests with the air moving in one direction, with different velocities, and another set with the air moving in the other direction but with similar velocities, the influence of the direction and the quantity of air current can probably be determined within reasonable limits.

POWER PLANT.

The power plant consists of one 60-horsepower boiler of locomotive type, placed in a galvanized-iron boiler house sufficiently large to permit the erection of a duplicate boiler. There are the necessary steam appliances, hot-water heater, pump, and other fittings. The engine plant is in an annex to the boiler house, and consists of an 8-horsepower steam-generator set, the speed regulation of which is close with change of load.

The generator set is for the purpose of supplying electricity for the recording instruments and for lighting the mine, stations, and buildings. It is expected that in the future a sufficiently large generator set will be installed to enable experiments to be made with electric machinery, electric motors, and electric coal cutters. Since the first series of tests, a single-stage air compressor with a capacity of 174 cubic feet of air per minute at atmospheric pressure and capable of compressing to 100 pounds has been installed for the immediate purpose of running a "puncher" air machine. In the next series of experiments compressed-air jets assisted by the fan will be tried for cleaning the dry dust and soot from the shelves and the walls of the entries.

COAL-DUST AND ROCK-DUST GRINDING PLANT.

For extensive coal-dust experiments such as have been planned, a large quantity of coal dust will be required. For example, if 2,000 feet of entry is to be loaded with coal dust to an extent of 2 pounds per linear foot, 4,000 pounds or more will be necessary. Sufficient coal dust made in the ordinary way can not be easily obtained, nor is it uniform when procured. Therefore the dust is made artificially from the coal mined at the face. In order to obtain comparable results when making coal-dust explosion tests, the coal after having been crushed is uniformly ground until 95 per cent of it will pass through a 100-mesh sieve, as determined by frequent tests of samples. During the first series of experiments the crushing and grinding machinery had not been completed, and the coal dust had to be ground at the Pittsburgh station. For the second series all of the dust will be ground in the mine plant.

The crushing and grinding plant is housed in a building, the first story of which is concrete, the upper part being of galvanized iron on wood framing.

The coal, or the rock if rock dust is desired, is transported in mine cars to the second floor of the building and shoveled on a bar screen with 4-inch spaces, and the larger pieces are broken by sledge until they pass through; a hopper receives the screened material and delivers it to a hammer crusher which breaks it into smaller pieces three-eighths of an inch in diameter and finer. From the crusher the coal is taken by an elevator to a bin that feeds the pulverizer.

The pulverizer is an impact machine. Its essential part is a beater with two blades, which revolves in a steel-lined box at a speed of 2,700 revolutions per minute. The blades break and pulverize the material, and act as fans, the effect of which, assisted by the suction from a large fan above, is to lift the finely ground material through a conical separator provided with deflectors. The air current rising through the separator with a lessening velocity, caused by the enlarging cross section, has a sorting action; the coarser particles drop back and the finer dust is drawn upward to the fan. There are dampers at the top of the separator which can be adjusted to control the air current and cause the coarser dust to fall back to the beaters for finer grinding. On passing through the fan the dust is blown into a large upright pipe which connects above to a "cyclone" collector which gathers all but the lightest dust. The lightest dust and the excess air from the top of the collector are blown into an adjacent collector consisting of a large number of cotton tubes or "stockings," by means of which even the finest dust is strained out as the air discharges through the fabric. The dust gathered by the "cyclone" and the tubular collectors drops through pipes into a tight steel-plate bin.

There is practically no loss of dust. The steel bins are covered in order to lessen the danger from an explosion of dust in the house, and to save the float dust, which, when pure, is probably very dangerous in mines, so that its inclusion with the coarser dust is essential in making tests of the explosibility of coal dust.

On the second floor of the house there is a mine-car track which runs out on the level of the yard sidings. The dust bin is above the track, so that cars can be loaded and taken into the mine with little labor. The crushing and grinding plant will also prepare rock or shale dust to be mixed with coal dust, or placed on shelves, or used in other ways in the tests for preventing or checking coal-dust explosions.

COAL-HANDLING EQUIPMENT.

When entries or rooms are being driven, the loaded coal cars are hauled from the mine by mules or by gasoline motors. The track has a slight down grade from the mine to passing tracks in the vicinity of the boiler house, grinding house, and blacksmith shop, into each of which cars may be run for the easy handling of timber and other material. At the lower end of the yard there is a gas-engine hoist for lowering the mine cars down an incline to the tipple and pulling back the empty cars.

As coal is mined only in extending the headings and in preparing for experiments, the tipple structure is simple, and there are no screens.

WATER SUPPLY AND FIRE PROTECTION.

There is a rivulet in the ravine in front of the mine. An earth dam has been thrown across to make a reservoir. The water is of good quality for boiler supply. A steam pump discharges the water into a 5,000-gallon tank on the hillside above the mine, at an elevation that gives a pressure head suitable for fire fighting—40 pounds per square inch at the mine hydrants.

OBSERVATORY AND CONTROL STATION.

Situated on the hillside, commanding a view of the three entrances to the mine, is the observatory and control station (Pl. III, *B*). It is built of reinforced concrete, the roof being constructed of railroad rails covered with concrete. The front wall, the one facing the mine, is 2 feet thick, and has small windows through which the external evidence of the experiments can be watched in safety. The external recording instruments, the chronographs, time markers, circuit-breaker recorders, and other instruments, as well as the shot-firing connections and firing buttons, are in this building. A detailed discussion of the instruments is given in the section of this report entitled "Description of Instruments for Measurement of Velocity and Pressure."

UNDERGROUND EQUIPMENT.

It has already been mentioned that tracks are run through the entries to allow easy handling of materials, as well as the transportation of the coal mined at the face. The mine is now equipped with 24 coal cars and one car for concrete work. For coal cutting there is a supply of hand augers, picks, shovels, and other tools. Recently, since the end of the first series of tests, an air compressor has been added, also an air "puncher" machine with which a 5-foot undercut can be made.

A 2-inch water line is installed along the main entry, and another line through the diagonal heading into the air course. These pipe lines are placed in grooves behind the concrete lining, or where there is no lining, in grooves in the coal, the grooves being faced with concrete. The pipes are thus protected to prevent damage during experiments. There are hydrant boxes every 100 feet for attaching hose for fire protection and for washing down or wetting the coal dust.

COAL-DUST SHELVING.

Before making coal-dust explosion experiments it was necessary to plan adequate arrangements for loading the mine headings with coal dust. It is important that the test conditions can be duplicated from time to time. In the surface galleries there is an iron, wood, or concrete floor, which can be swept clean after an explosion test. In the Liévin gallery, in France, the dust is spread on the floor (concreted at the inner end, wood covered at the outer end), and the cleaning is accomplished by increasing the speed of the fan and then raising the dust with a compressed-air jet from a hose, the cleaners beginning at the inner end of the gallery and with the jets and ventilating current sweeping the dust before them. In mine entries or headings it is much more difficult to arrange for placing the dust, because frequently the floor, ribs, and roof are damp. The roof and ribs are uneven except in the concreted sections, which form a small part of the whole mine. The floor is naturally rough on account of the track and ballast.

In the Altofts gallery, in England, the coal dust was placed on light temporary shelving of one-half by 5 inch boards, which rested on brackets without fastenings. Whenever there was an explosion the shelving was torn down and broken to pieces. This shelving, however, was inserted along only 500 to 600 feet of gallery. In much longer passageways, like those of the experimental mine, replacement after each experiment would be too slow and too expensive.

For the experimental mine it was decided to use fixed and somewhat permanent wooden shelving (Pl. II, *A*) which could be kept reasonably dry and be easily cleaned. The shelving is made heavy, of 3 by 4 inch hard-pine material, in order to lessen breakage. It was thought that if the shelves were set close to the ribs and were continuous and smooth, like the rifling of a gun, they would not be seriously damaged. This generally has proved to be the case, except that shelving in front of an opening is liable to be broken down. The shelving is placed with the 3-inch side horizontal. In the lined sections bolts were set in the concrete wall during construction, so that each 16-foot length of shelving is supported by three ⅝-inch bolts, which pass through the timber; the bolts are drawn up, pressing the shelving tightly against the concrete. (See fig. 5.) In the unlined portions of the entry 8 by 8 inch posts are used to support the shelves (Pl. II, *A*); they are recessed into the ribs so as to present little or no projection for the pressure wave to strike. However, in a few tests some of the posts, in spite of being wedged, have been drawn out of the recesses, presumably by the depression wave following the explosion waves. It has therefore been necessary to anchor the posts to the ribs by bolts set into drill holes in the coal rib and cemented.

At the time of the first two official tests the shelving arrangements had not been completed, so that it was necessary to set up temporary props and place the shelving without fastenings. The result was that in the tests all the shelving throughout the mine was thrown down; some of it was broken, and many pieces were blown out of the mine to the hillside opposite.

INSTRUMENTS USED IN THE FIRST SERIES OF TESTS.

In the study of coal-dust explosions it is desirable to have flame and pressure records at as many points along the course of the explosion as practicable. It is important that each record should show the rise and fall of each pressure or depression wave that passes the recording instrument; it is equally necessary that each record should have the same time intervals marked upon it, so that the records made at successive points may be compared; and it is of the utmost importance that the position of the forward point of the flame and its duration with reference to the curves of the pressure waves shall be obtained at the various stations. The instruments used at Liévin photograph the flame directly on the manometer films on which the pressure records are photographically recorded. The instruments used at Altofts and at the experimental mine in this series of tests record the position of the flame by a separate apparatus; therefore, to obtain a comparison it is necessary that the flame records have the same time intervals as are registered on the pressure manometer records. The French method has the obvious advantage of the records being made by the same instrument.

It was intended before the first series of tests was started to have all the various kinds of instruments used in the foreign testing galleries, and, if possible, to design and make new instruments better adapted for the particular conditions at the experimental mine, but circumstances prevented getting any but the British coal-dust instruments, like those used at Altofts. The investigations at Altofts and at Liévin were conducted in galleries above ground, so that there was little difficulty in the attachment or placing of delicate recording instruments, which could be set up on the exterior of the gallery and connected through openings in the walls. In using instruments in the experimental mine it is necessary to protect them from the action of the pressure and the flame from an explosion by placing them in special chambers (Pl. V, *A*, and fig. 7) as nearly gas-tight as possible, lined with reinforced concrete, and located in the side of the entry.

RECORDING MANOMETERS.

For recording the pressures three B. C. D.[a] manometers similar to those designed for the experiments at Altofts were purchased. Two of these were used for high pressures and one for pressures below atmospheric pressure. These manometers are somewhat similar in principle to a steam-engine indicator and are described in detail in the chapter entitled "Description of Instruments for Measurement of Velocity and Pressure." The connections from the instruments to the main entry are made through a heavy ribbed steel-plate casting 1½ inches thick, which is designed for a pressure of 500 to 600 pounds per square inch. The casting is set in the concrete wall of the chamber flush with the side of the entry. The instruments are placed on a wide shelf, with sufficient space behind them to allow manipulation. The cables carrying the wires for the electric circuits are in a 4-inch pipe behind the concrete lining of the entry and enter the instrument chamber under the shelving. Access to the chamber from the entry is had through a side passage. The entrance door is a heavy steel casting, designed to withstand a pressure of 500 to 600 pounds per square inch. The construction of a station is shown in figure 7.

Four instrument stations of the kind described were constructed, two in the diagonal heading and two in the main entry. These stations are at 100-foot intervals. For the next series of tests addi-

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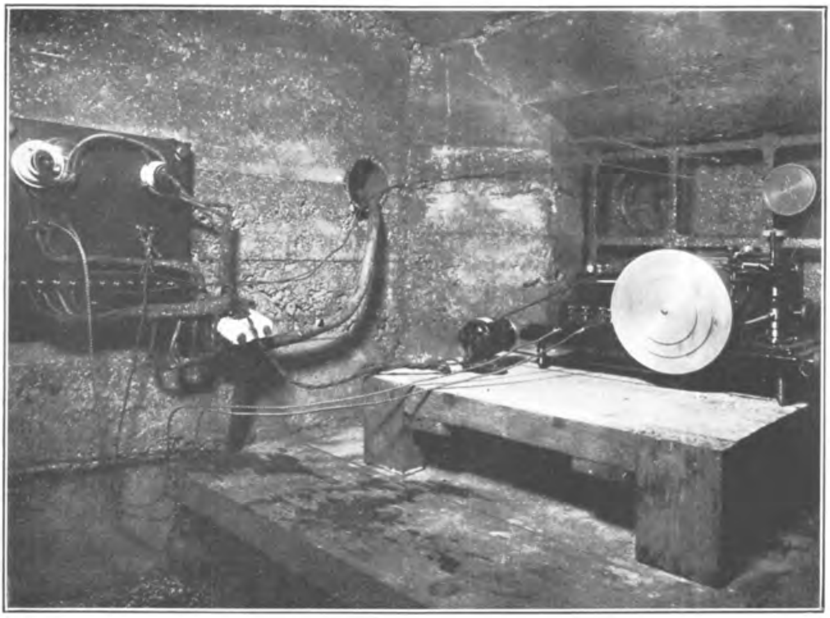
[a] See p. 57, footnote.



A. INTERIOR OF INSTRUMENT STATION, SHOWING B. C. D. MANOMETER.

B. DÉBRIS ON HILLSIDE OPPOSITE MINE ENTRANCE.

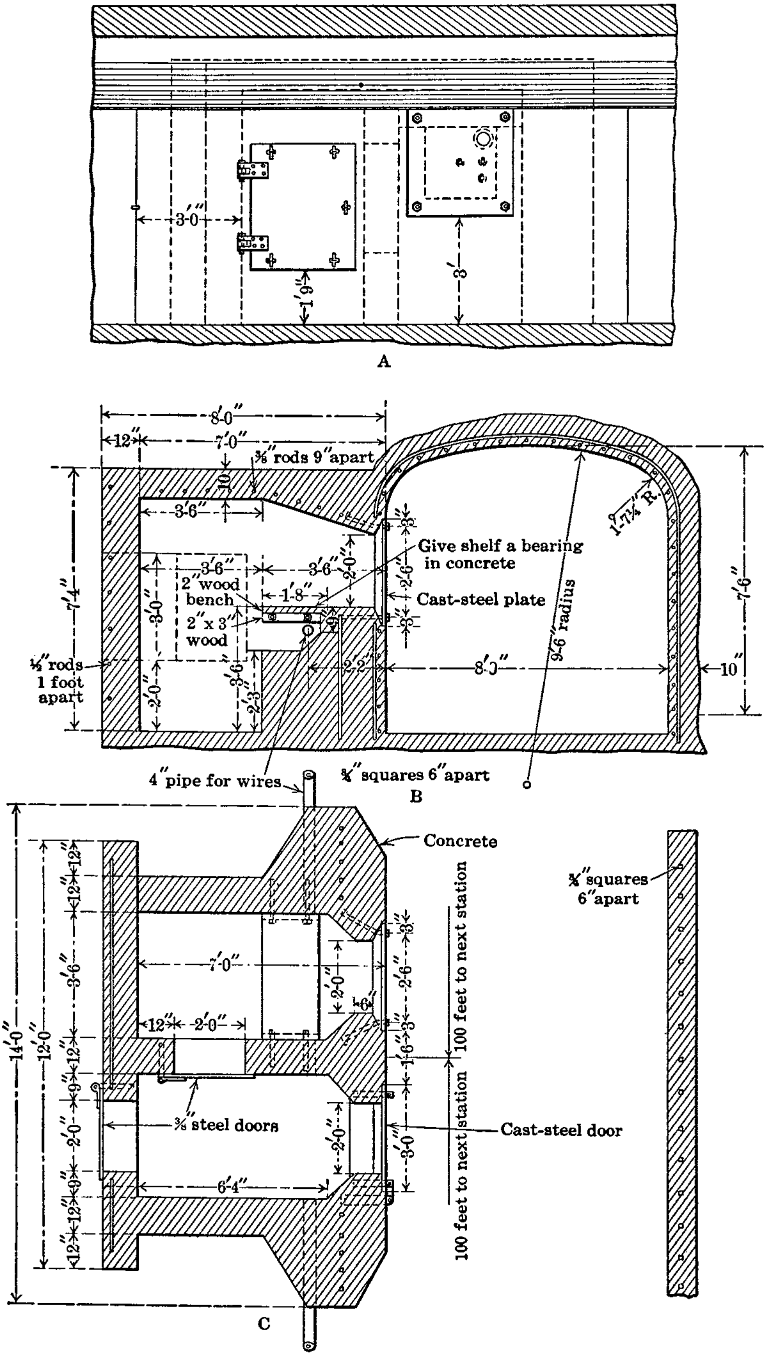


FIGURE 7.—Construction of instrument chamber: A, front elevation; B, vertical section; C, plan.

tional instrument stations will be constructed, probably at intervals of 200 feet.

MAXIMUM-PRESSURE GAGES.

In the later tests of the series the recording manometers were supplemented by maximum-pressure gages.[a] They are similar to those used by Taffanel at Liévin, being of the type employed in this country and abroad in gunnery tests. The maximum-pressure gages are placed in boxes with iron-plate fronts, into which the gages are screwed, and are set in the side of the entry at 100-foot intervals. The explosion pressure acts through a steel plunger upon a small copper cylinder or column, the relative compression or shortening of which measures the maximum pressure at that point. As the copper cylinders or columns furnished with the pressure gages had not been made with sufficient care, the records obtained in the first series of tests were unreliable. It is expected that gages of better construction will be used in the future.

VELOCITY-RECORDING INSTRUMENTS.

The velocity of the flame and that of the pressure wave of the explosions were measured by the automatic recording on the chronograph of the respective times at which the flame or the pressure wave passed each station. The stations were at 100-foot intervals. The recording was accomplished by placing in the stations pressure circuit breakers and flame circuit breakers. The former operate by the action of pressure on a plunger, breaking a circuit. Two different types of flame circuit breakers were used—the detonator type and the tin-foil type. They are fully described in a subsequent section, entitled "Description of Instruments for Measurement of Velocity and Pressure."

The circuit breakers above described are placed in the rib in air-tight concrete boxes with hinged steel doors (Pl. VI, *A*). The circuit breakers are attached to the doors, so that when the doors open they may be readily inspected and connections made to wires leading to the outside observation station.

ELECTRIC CABLES.[b]

The cable carrying the wires to the various electrical instruments runs through an iron pipe set in a deep groove in the coal. The groove is faced with concrete to provide protection for the pipe and support for the coal rib. The cable is cut at each instrument chamber, and the wires are connected to binding posts on the switchboard at the back of the chamber.

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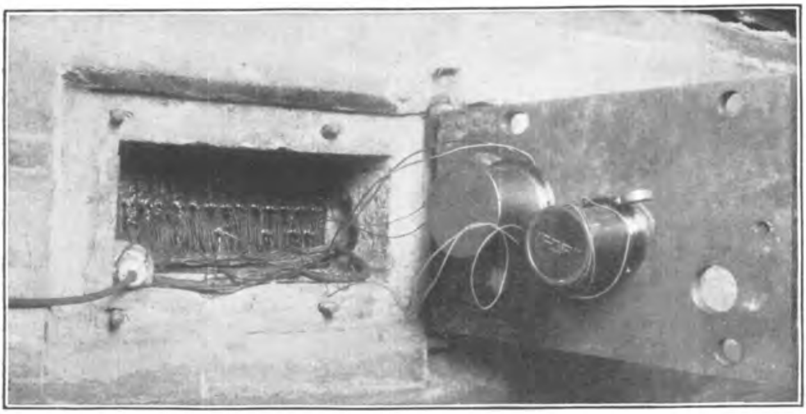
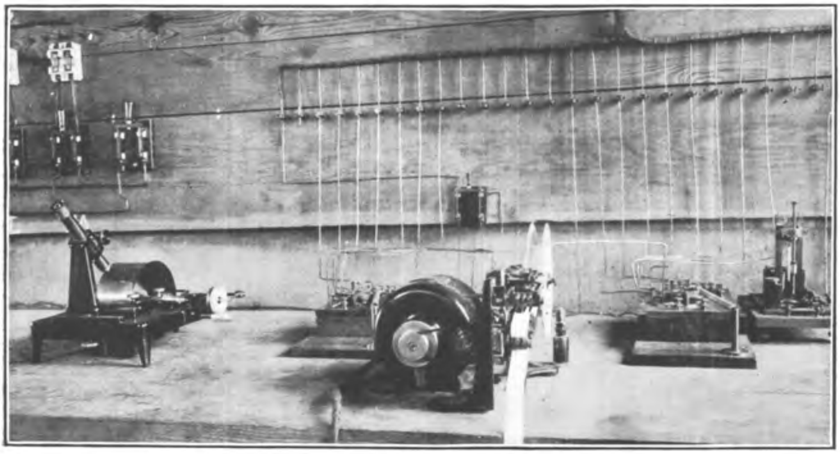
[a] Described on pp. 59, 60.

[b] See also discussion under section entitled "Description of Instruments for Measurement of Velocity and Pressure."



A. CIRCUIT BREAKERS IN SMALL STATIONS.



B. OBSERVATORY WIRING CONNECTIONS.

C. RUPTURE OF LINING OF MAIN ENTRY.

FIRING CIRCUITS.

Among the other wires of the cables are a pair of firing wires that can be connected to form a circuit in the observatory and thus discharge the igniting shot. In the first two official experiments this wiring was temporary, but subsequently when the flame and pressure circuit wires were installed the shot-firing wires formed a part of one of the cables passing through the pipe in the rib.

The shot-firing wires are separated from the other wires at the mouth of the mine and enter a locked switch box.[a] This box contains switches, which are always open until everyone has left the mine.

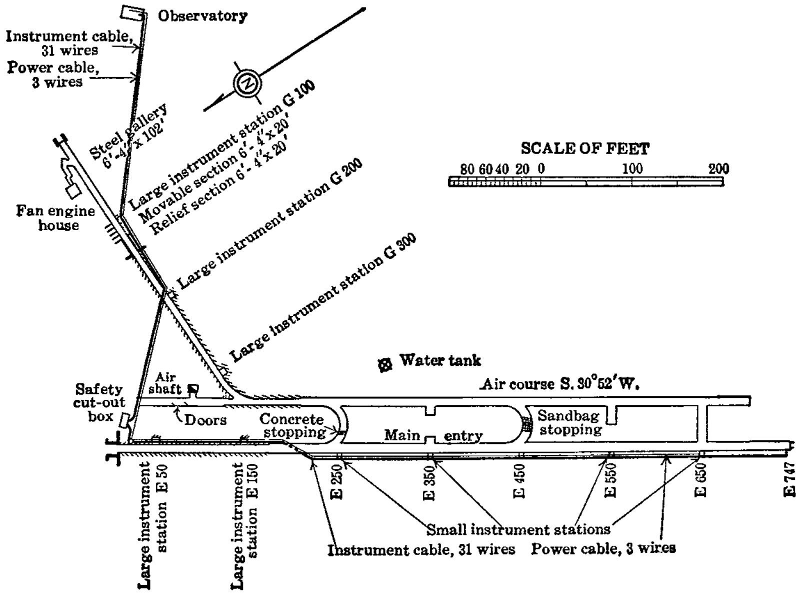


FIGURE 8.—Electric wiring of mine.

At the observatory there is another switch, also in a locked box. This switch is closed by the engineer in charge of the experiment after he has thrown in the switch at the mouth of the mine; that is, he carries the keys to both boxes, so that he may make sure that everyone has left the mine before he throws in the switches. When the switches are both in, the firing circuit is completed by pressing a button that causes the shot in the mine to be discharged. The details of the wiring are given in a subsequent section of this bulletin and a diagram of the wiring is shown in figure 8.

[a] After the first series of explosions had been completed, with a view to greater safety the installation was changed. Now all the wires enter the locked box and are arranged so that all the circuits are cut by switches when men are in the mine.

CHEMICAL ANALYSES.

In order to study the chemical processes accompanying an explosion, analyses of the coal dust used and of the residual solids left after the explosion—that is, coked dust and condensed hydrocarbons—are required so that the changes in the composition of the dust and the loss in gaseous constituents may be determined. Representative samples of the coal dust may easily be taken previous to an experiment, but it is not so easy to obtain average samples of the solid residues of the explosion, and it is practically impossible to recover the total quantity of the residues.

AFTERDAMP SAMPLING.

Samples of the afterdamp may be obtained some minutes after the explosion by men wearing oxygen helmets such as are used in rescue work. It is important, however, to obtain gas samples at intervals during the explosion as well as immediately after the explosion.

This can be accomplished only with the use of automatic apparatus, like that used in the investigations at Altofts and at Liévin.

The B. C. D. automatic sampler [a] (Pl. VII, *A*) used in the first series of tests at the experimental mine was opened by a circuit maker operated by pressure. On account of the difficulty in predetermining accurately the relative velocities of the pressure wave and the flame, the attempts during the first series to obtain gas samples during the passage of the flame were not successful. Also, in some tests the projecting pipe connections were carried away by the force of the explosion. It is planned in future experiments to have gas samplers operated by means of the flame circuit makers, to have no projecting parts, and to use devices for quickly closing the sampling bottles after the sample has been admitted.

A new type of automatic gas sampler is being developed at the Pittsburgh station for taking a set of three successive samples during or following the passage of the flame. The sampler is set in operation by a flame circuit breaker. The first sample is taken instantaneously; the others are taken at predetermined intervals by means of clockwork mechanism.

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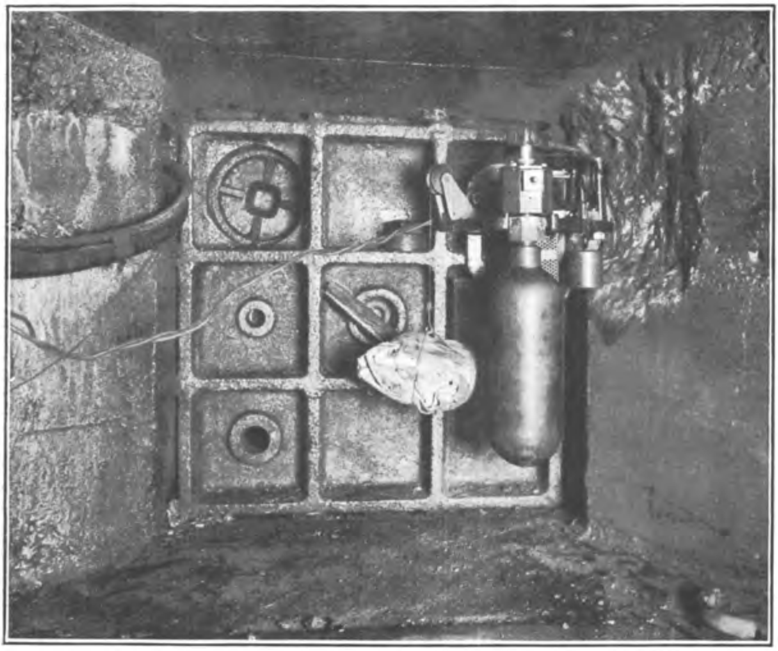
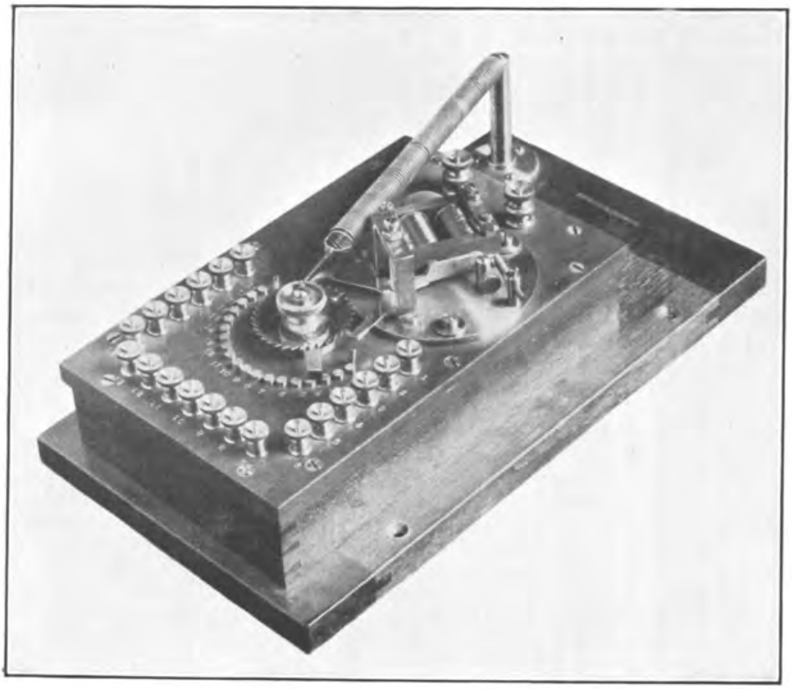
[a] See full description under "Description of Instruments for Measurement of Velocity and Pressure."



A. B. C. D. AUTOMATIC GAS SAMPLER.



B. B. C. D. AUTOMATIC COMMUTATOR.

GENERAL DESCRIPTION OF EXPERIMENTS.

PRELIMINARY EXPLOSION TRIALS.

The original plan was to make explosion experiments at intervals while the mine was advancing, the explosions being originated in the exterior gallery. In other words, the ignition of coal dust was to be accomplished in the gallery in a manner similar to that employed at the Pittsburgh gallery, namely, by simulating a blown-out shot of black powder or dynamite at the closed end. However, the farther end of the Pittsburgh gallery was open, whereas at the experimental mine the farther end of the gallery, although unobstructed, pointed directly into the mine. The cannon for simulating the blow-out shot was placed against a plank stopping that closed the outer end, and a hole was cut through the stopping opposite the bore of the cannon.

Coal dust was placed along the floor of the gallery. When the large relief opening, or the movable section for connection to the mine was rolled to one side, there was no difficulty in obtaining ignitions similar to those at the Pittsburgh gallery. When, however, the large openings were closed, the effect was striking. The plank stopping was burst outward by the effect of the shot and the dust was inflamed only in the first half of the gallery. On strengthening the stopping, the flame was projected feebly through the gallery, but died away on entering the mine. Force was manifested in the vicinity of the cannon, breaking some of the heavy planks of the stopping and throwing down a sandbag stopping in the branch to the fan, but the force in the direction of the mine diminished rapidly. Seemingly the concussion of the blown-out shot did not bring the coal dust into suspension at a distance from the cannon, and the pressure developed by the ignition of the dust near the cannon, being relieved by the breaking out of the stoppings, was not sufficient to cause pressure waves large enough to continue to raise in advance coal dust in quantities sufficient to sustain propagation.

EXPLOSION TEST 1.

Several attempts of the foregoing sort were made and resulted in considerable damage to the temporary fan casing. As the time was getting short for preparing a public demonstration in connection with the first national mine-safety demonstration on October 30–31, it was decided on October 24 to see whether a blown-out shot at the face of the main entry would start an explosion. The result was surprisingly successful. Flames shot from every opening, and there was a loud report. A car standing 50 feet from the mouth of the entry was blown off the dump, evidently being lifted over a gasoline locomotive, as indicated from certain marks on the locomotive. The locomotive was moved 15 feet. The details of the experiment are reported on pages 66 to 69. The intensity of the explosion was a surprise to the observers. Considerable damage was done to the mine, including cracking of the concrete in the main entry and in the air course at the junction of the diagonal heading. There had been a 6-foot sandbag stopping in the air course at this point, the sandbags being tightly wedged in. As the explosion came outward on the air course, the rush of the gases was momentarily arrested by the stopping, which probably acted like a water hammer to produce great increase in pressure, causing the concrete roof to be lifted and to lift up with it the upper part of the corner pier. A piece of board and some brattice cloth were blown into the break as the roof lifted, and when it dropped it nipped the cloth and stick, as shown in Plate VIII, *A*. Meantime the sandbag stopping had been thrown outward, some of the bags to the outside of the mine. After the rush of the hot gases to the outside, there was a return wave to fill the partial vacuum; this carried a few of the sandbags inby their former position.

The pressure manometers at stations 150 and 50 feet, respectively, from the mouth of the mine indicated a velocity of the pressure wave between these stations of 1,954 feet per second. In this test the manometers were equipped with 30-pound springs. The pressure at station E 150[a] exceeded the capacity of the spring, and the record was interrupted by the stylus being thrown off the smoked paper. The actual pressure at station E 150 was probably greater than 50 pounds. The highest pressure recorded at station E 50 was 40 pounds.

The chief lessons to be learned from this first formal test were:

(1) That an explosion could be obtained by a single blown-out shot at the face;

(2) That the reinforced-concrete lining was not sufficiently strong in itself to prevent rupture when an explosion approached the detonating stage;

(3) That the instrument stations were satisfactory in their construction;

(4) That the general arrangement of the mine was very satisfactory;

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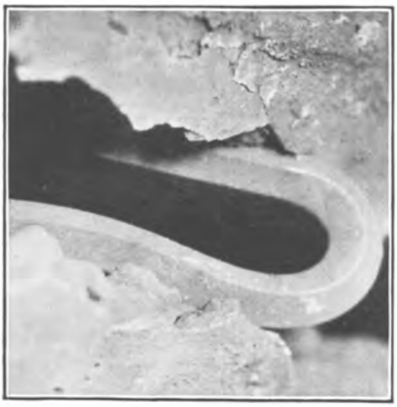
[a] Text and figure references to stations E 50, E 150, etc., and to stations G 200, G 300, etc., refer to stations placed in the entry or in the gallery at points distant from the mouth of either the number of feet designated by the figures attached to the initial.

A. RESULTS OF TEST 1 AT JUNCTION OF SLANT AND AIR COURSE.



B. BENT $\frac{5}{8}$-INCH STEEL BAR, SHOWING LIFT OF ROOF.

C. REINFORCING ROD PULLED OUT OF CONCRETE IN ROOF OF MAIN GALLERY.

(5) That temporary shelving for coal-dust load was unsatisfactory because its replacement causes serious delays in conducting consecutive experiments.

EXPLOSION TEST 2.

Although it was a rainy day, probably 1,500 people visited the mine to witness explosion test 2 on October 30, 1911. Nearly 1,200 people went through the mine previous to the test. Unfortunately delay was experienced in discharging the igniting shot prepared at the face of the main entry. This delay was due to some short circuits in the shot-firing lines, probably caused by visitors accidentally trampling on the wires. Eventually a temporary line was carried into the mine and the blown-out shot was fired. The resulting explosion was most spectacular, happening as it did on a dark, rainy night. The flame was of great extent and most vivid, and the concussion was felt in villages 4 miles distant; it is claimed to have been heard at Monongahela City, 12 miles distant.[a]

Details of this test are given on pages 69 to 78.

The motors driving the manometer drums failed to start when the switch was thrown in at the observatory, so that no record of the pressure wave was obtained; only the maximum pressures were indicated, which were 26.5 pounds per square inch at station E 150 and 21.3 pounds at station E 50. There is great doubt whether these values represent the maximum pressures. The demonstrations of violence were apparently greater than in the previous test, in which the manometer readings showed higher pressures.

The lessons to be drawn from this experiment are:

(1) Coal-dust explosions may occur when the atmosphere is nearly saturated (the relative humidity within the mine was over 90 per cent) and the floor, ribs, and walls are damp, but not wet, provided the coal dust is dry and sufficiently abundant.

(2) Temporary shelving, being easily wrecked, is too expensive.

(3) There were too few recording instruments to obtain the information necessary to study satisfactorily the phenomena of a dust explosion.

(4) The magnitude of the lateral pressure of the main explosive wave of a coal-dust explosion was demonstrated by the 13-inch lift of the concrete arching in the main entry near station E 50, and by the lift of the arching in the diagonal heading, which for its entire length of over 200 feet was lifted bodily, the reinforcing rods being pulled through the concrete. This lift was about 12 inches, judging from one piece of reinforcement that was doubled back on itself (Pl. VIII, *B*). Not only did the strength of the lining have to

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[a] An account of this explosion is given in Bull. 44, Bureau of Mines, entitled "First National Mine-Safety Demonstration, Pittsburgh, Pa., Oct. 30 and 31, 1911," by H. M. Wilson and A. H. Fay, with a chapter on "The Explosion at the Experimental Mine," by G. S. Rice, 1912, pp. 29–41.

be overcome, but also the weight and resistance to shearing of 6 to 12 feet of natural strata, shale and clay, overlying the arching.

The breaking of the lining of the diagonal heading was a temporary misfortune, as it prevented resumption of experiments in originating explosions at the mouth of that heading, both because of the weakness of the cracked lining and because the breaks allowed ground water to run in freely, keeping the gallery wet. So much damage was done in the mine that several weeks was needed to make repairs. While the repairs were being made, the permanent shelving was put in place, the small stations installed for the circuit breakers, and the permanent wiring put through a line of 4-inch pipe to the head of the main entry. For safety, the pipe was set in a groove in the rib. With the small force of laborers permitted by limited funds, these repairs and improvements were not completed until the latter part of January, 1912, when the mine was put in readiness for further tests.

EXPLOSION TEST 3.

In order to test the new permanent shelving it was decided to first try explosions limited in length and, if these were successful, to increase successively the length and intensity of the explosions. The coal-dust zone in test 3 was therefore made only 84 feet long—measured from the face in which was the blown-out shot to the outer end of the zone.

It was also thought advisable in this series of experiments to make some preliminary tests of stone dust placed on shelves. Such experiments were made at the Altofts gallery, England, also independently and more fully by Taffanel at the Liévin gallery, where a special arrangement of them is termed l'arrêt-barrage ("arresting barrier"). In consequence of the success of Taffanel's tests, the plan of using the barriers has been generally adopted in French mines. The "arresting barrier" is composed of 10 or more shelves about one-half meter (20 inches) wide. Finely ground rock or shale dust is heaped upon them. The shelves are placed sufficiently high to give clearance for the cars, but a small space is left between the heaped-up dust and the roof, each shelf and the heaped-up dust occupying about 10 per cent of the cross section of the entry. The arrangement is such that when an explosion strikes the barrier the shelves are knocked down or demolished and the dust thrown into the air, forming what has sometimes been termed "a dust curtain," which in the Liévin gallery has been found to check or stop the explosion.

For test 3, made January 31, 1912, a set of "arresting-barrier" shelves was placed in the air course immediately outby the inmost cut-through, which was left open for ventilation. As the coal-dust loading was limited, the explosion or inflammation was small and without violence. The effects on guncotton tufts suspended at intervals along the entry indicated that the flame traveled over 159 feet from the point of origin, or nearly double the length of the coal-dust zone. The branch flame that extended through the open cut-through was 63 feet long, and did not extend through the barrier. The latter result, however, was not conclusive, as the stone dust was very little displaced. There were no indications of violence. For details of this test see pages 78 to 80.

EXPLOSION TEST 4.

Test 4 followed test 3 on the same day (Jan. 31, 1912), the object being to determine whether there was sufficient unaffected dust left from the previous explosion to reignite and propagate the ignition. It was noted that the bulk of the dust had not been displaced from the shelving. No new dust was placed on shelves, but some fresh dust was placed in front of the igniting dust, and the experiment was made under practically the same conditions as present in test 3. The results were practically identical, the flame probably going about the same distance.

EXPLOSION TEST 5.

The object of test 5, made February 2, 1912, was to determine what pressures should be placed on the circuit breaker so that the record of the pressure wave from the dust explosion would not be influenced or affected by the wave from a blown-out shot of 2 pounds of black powder.

As the pressure resulting from a coal-dust explosion is at first low, it is desirable that the circuit breakers be adjusted to operate at low pressures. If, on the other hand, they are adjusted to release at too low a pressure, they will be operated by the pressure wave set up by the blown-out shot. In test 5 no coal-dust load was used, and the entry was thoroughly wetted. In order to be assured that the result would not be influenced by the presence of methane, the fan was shut down for 14 hours preceding the test, and samples of air were taken at the face before the fan was started. The samples contained only 0.06 and 0.04 per cent of methane. The sample of mine air taken at the face the following day, under normal conditions of ventilation, contained only 0.02 per cent of methane. Two pressure circuit breakers were installed at station E 650, one being set to release with a 1-pound and the other with a 2-pound pressure. Only the one set for a 1-pound pressure operated, and it was therefore concluded that circuit breakers set for a 2-pound pressure would not be operated by the pressure from a blown-out shot of the size mentioned from a cased hole in the coal.

EXPLOSION TEST 6.

In test 6, made February 3, 1912, the coal-dust load was 190 feet in length, or over double that used in tests 3 and 4. A stone-dust barrier like that described under test 3 was erected in the air course immediately outby the open crosscut. The main entry was left open. The results were that the flame, after having passed through the cut-through into the air course, died away after having passed the first two or three shelves, but the ground rock dust on these shelves was little displaced; and it is questionable how far the flame was checked by reason of the presence of the barrier. In the main entry the flame traveled about 70 feet beyond the coal-dust zone, but there was no indication of local violence.

In this test a record of the flame velocity between stations E 650 and E 550 was obtained, and showed that the distance of 100 feet was traversed in 0.7903 second, or at the rate of 127 feet per second. (See fig. 10.) For details of this test, see pages 83 to 87.

EXPLOSION TEST 7.

Test 7 was made February 5, 1912, with an increased length of coal-dust load, the length being 290 feet, or 100 feet more than in the previous test. Determination was desired of the effect of the rock-dust barrier when the length of the coal-dust zone was increased. The results showed that while the flame died away in passing through the barrier, the rock dust was little disturbed, except on the first shelf or two. In the main entry the flame traveled 465 feet, or 175 feet beyond the end of the coal-dust zone. The humidity of the air at the mine in this test, as well as in the previous one, was rather high, ranging from 93 at station E 450 to 100 per cent at station E 650 opposite the inner cut-through. The velocity of the flame between stations E 650 and E 550 was 160 feet per second. (See fig. 10.) For details of this test, see pages 87 to 91.

EXPLOSION TEST 8.

Test 8, made February 7, 1912, was virtually a repetition of the previous experiment. The coal-dust load and other conditions were the same, except that the relative humidity of the air was considerably less, being 85 per cent at station E 450 and 83 per cent at station E 650 opposite the inner cut-through. It should also be noted that the fan was shut down two minutes before the test was made, although this may not have affected the results. Perhaps the most influential cause of difference was that instead of making the blown-out shot in the coal face, as had been done in the previous tests, the ignition was caused by a blown-out shot from the cannon, which was placed at the face. The cannon probably produced a greater local concussion of the atmosphere, and thus the explosion may have been started with greater strength. In the main entry the flame was 552 feet in length, and therefore passed 262 feet beyond the end of the zone of loading, as compared with 175 feet in the previous test. There was also much more physical manifestation of violence at the mouth of the mine.

The pressure wave between stations E 650 and E 550 had a velocity of 1,136 feet per second, and between stations E 550 and E 450 of 1,116 feet per second. This wave was probably that produced by the shot of the cannon and did not represent the explosion wave which followed it. The flame circuit breakers at the 100-foot stations between E 650 and E 250 showed velocities of 220, 254, 398, and 51 feet per second, thus indicating that the inflammation was relatively slow, and was dying away when it reached station E 250. (See fig. 10.) The last evidence of flame as shown by tufts of guncotton was 58 feet outby station E 250. Manometric pressure readings were not obtained, except for pressures below atmospheric, following the explosion. The curve obtained is shown in figure 21. The maximum depression was about 1 pound per square inch, and the total period of depression was one-fourth of a second only. The details of this test are given on pages 91 to 95.

EXPLOSION TESTS 9, 10, AND 11.

In test 8, pressure circuit breakers set to release at a pressure of 2 pounds were seemingly operated by the pressure wave from the blown-out shot from the cannon. Further tests were required, therefore, to determine the minimum pressures at which the circuit breakers might be set without risk of being operated by the wave from the cannon. In test 9, made February 8, 1912, and in tests 10 and 11, made February 9, 1912, no coal-dust load was used, and the entry was wet down with hose. The cannon was loaded with $2\frac{3}{4}$ pounds of black blasting powder, with 4 inches of clay stemming. In test 9 there was one circuit breaker at each station, and all were set to release at a 2-pound pressure; all were operated on the discharge of the shot. In test 10 two circuit breakers were installed at station E 650, one set to release at a 3-pound pressure, and one at a 4-pound pressure; both were operated by the shot. In test 11 the two circuit breakers installed at station E 650 were set, one to release at a 5-pound pressure and the other at a 6-pound pressure; neither was affected by the pressure from the shot.

As a result of these tests it was decided that in future tests when the coal dust was to be ignited by a shot from the cannon the pressure circuit breakers should be set to release at a pressure of 5 pounds. The tests demonstrated what has been suspected—that a blown-out shot from a cannon causes a higher air pressure than a shot of the same weight of charge placed in the coal face, even when a pipe liner is used, because some of the energy of the exploding powder is expended in breaking the liner and the surrounding coal.

In tests 5, 9, and 10 tufts of guncotton were suspended at intervals along the entry. All of them within a distance of 40 feet from the cannon were ignited, probably not by flame but by burning particles of powder projected by the shot. This conclusion was reached as the result of tests in the Pittsburgh station gallery.

EXPLOSION TEST 12.

In test 12, made February 10, 1912, a lighter coal-dust load was used than previously, the quantity being 1 pound per linear foot for the first 290 feet, and less than one-half pound (0.457 pound) per linear foot for the outer 420 feet.

The flame did not travel to the outside of the mine, but stopped at about 465 feet from the origin, or at 175 feet beyond the end of loading of 1 pound per linear foot. Judging from the one experiment of this character, it would appear that under the existent conditions 0.457 pound of dust per linear foot was not sufficient to propagate an explosion. The quantity mentioned is equivalent to about 0.122 ounce per cubic foot (122 grams per cubic meter) of air space. The humidity was high, but not extremely so, being 91 per cent at station E 650. In this test the flame did not pass beyond the barrier.

As the explosion in the main entry died away before reaching the manometer stations, the pressure produced had dropped so low that no pressure record was obtained; but following the explosion the suction manometer at station E 50 showed a depression wave lasting 0.6 second, the maximum depression being only 0.5 pound per square inch (see fig. 23). The velocity of the flame between the circuit breakers at the 100-foot stations between stations E 650 and E 350 indicated velocities of 153, 161, and 225 feet per second (fig. 10), showing that the explosion was relatively slow and feeble. The details of this test are given on pages 97 to 99.

EXPLOSION TEST 13.

Test 13 was made on the same afternoon, February 10, 1912, as test 12. The same dust was used except that 25 pounds of fresh dust was spread in front of the blown-out shot, which was prepared in the coal face, instead of using the cannon as in the previous test. The result was practically the same, the flame, as indicated by the tufts of guncotton, not extending further than in the previous test. Detailed description is given on pages 100 and 101.

EXPLOSION TEST 14.

In test 14, made February 19, 1912, the coal-dust load in the outer part of the mine was increased over that used in the previous tests;

throughout the mine it averaged about 0.93 pound per linear foot, equal to 0.248 ounce per cubic foot (248 grams per cubic meter). No preliminary watering was done.

The result was a sharp explosion, the flame issuing from the mouth of the entry with manifestations of violence. In the air course the explosion entered from the inner cut-through with considerable force, dislodged most of the shelving, and blew off the rock dust. This barrier, as in the previous tests, was located immediately outby the inner cut-through. The striking feature was that the flame did not pass beyond the barrier.

The motors driving the drums for the manometer failed to run, so that maximum pressures only were recorded at stations E 150 and E 50, the records being 14.7 pounds and 5.6 pounds per square inch, respectively. The relatively small load of coal dust was seemingly the cause of the pressures not being higher. Both the pressure and the flame circuit breakers failed to operate at some of the stations and thus prevented velocity records from being obtained. For details of this test see pages 101 to 105.

EXPLOSION TEST 15.

As test 15, made February 24, 1912, was the last test of the series, a public demonstration had been planned; consequently a number of State inspectors and other mining men were present. The coal-dust load per linear foot was double that previously used, averaging 2.13 pounds per linear foot, equal to 0.568 ounce per cubic foot (568 grams per cubic meter). It was also more extensively distributed than in any other experiment except test 2; it was spread throughout the main entry and two-thirds of the way in the air course. The rock-dust barrier shelving was changed from its position in the previous experiments to a point in the air course about halfway out in order to give it a more thorough test.

The result of the experiment was that the flame following the cloud of dust shot out of the main entrance accompanied by a loud, sharp report, and with manifestations of great violence. No flame appeared from the air-course entrance; the rock-dust shelves were demolished; the flame passed through the barrier, and traveled about 200 feet beyond, as shown by the ignition of tufts of guncotton suspended at intervals along the entry. It probably ignited the coal dust in a 50-foot zone that laid outby the barrier. In view of the great pressure existing within the air course, as demonstrated by the demolition of the barrier, it is quite probable that the flame might have reached the outside but for the rock dust dislodged from the barrier. However, the result as to the efficacy of the barrier must be considered inconclusive. A graphic representation of the probable extent of the flame is shown in figure 28.

Interesting, though incomplete, information as to the velocity of the pressure wave and of the flame was obtained from the instrument records. The pressure circuit breakers between stations E 650 and E 350 indicated velocities of 1,139, 48, and 980 feet per second. The first value, 1,139, probably represented the speed of the wave from the blown-out shot, and not of the explosion itself; the second value, 48, obtained by difference between the registration of the shock wave and the next registration by the explosion wave, must be disregarded; the record between stations E 450 and E 350 indicates that the pressure wave from the explosion had fairly started. (See figs. 9 and 11.) Farther out the pressure circuit breakers failed to work. The manometers at stations E 150 and E 50 indicated that the pressure wave had moved between the stations at the rate of 800 feet per second. The maximum pressures shown by the manometers were higher than previously obtained, the manometer at station E 150 indicating 103 pounds per square inch, and at Station E 50, 61 pounds. It will be noted in figure 27 that the pressure curves are incomplete, so that it is possible that higher pressures were attained than shown by the marks of the recording stylus. Following the explosion, the suction manometer at station E 50 recorded a depression lasting 3 minutes, with a minimum depression of 1.8 pounds per square inch. (See fig. 26.)

From the instant of ignition at the face until the pressure wave reached station E 350 the time interval was 2.367 seconds; the flame traveled the same distance (397 feet) in 2.537 seconds. The instruments indicated (if their relative lag be disregarded) that the flame at station E 350 was only 0.17 second behind the front of the pressure wave that acted on the pressure circuit breaker. (See fig. 9.) The successive readings of the flame circuit breakers between stations E 650 and E 450 were 408 feet and 1,351 feet per second; between stations E 450 and E 250 the tremendous velocities of 2,273 and 2,128 feet per second were indicated by the apparatus. Outby station E 250, on account of the failure of the automatic commutator to operate, records were not obtained. It would appear that the explosion was slow at the start but that by the time it had reached station E 450 it had approached a "detonating stage."

The most striking features of this experiment were the comparatively slow development of the explosion, the relatively slow speed of the pressure wave, and the rapid overtaking of the pressure wave by the flame of the explosion.

COMMENTS ON THE DATA OBTAINED.

Although the tests were too few, and the data obtained too meager, to admit of final conclusions being formed concerning the phenomena of coal-dust explosions, the results are of value in an educational way in demonstrating to the mining public the explosibility of coal dust when fire damp is not present, and the violence and destruction that accompany extensive coal-dust explosions, even when fire damp was not present. They were also useful in furnishing information to those conducting the investigation concerning the conditions under which coal-dust explosions may be brought about in the experimental mine, the kind of equipment required, and especially the character of instruments and apparatus necessary for properly recording and studying the phenomena of such explosions.

RECORDS OF PRESSURE VELOCITIES.

In the course of the experimental tests there were obtained records of five pressure waves in three experiments that were clearly "shock" waves started by the igniting shot. Two of these were registered when coal dust was not used, so that there is no question as to the correctness of the interpretation of their being waves started by the shot and not by the explosion of coal dust.

The velocities recorded were: Test 8, 1,136 and 1,116 feet per second; test 9, 1,111 and 1,099 feet per second; test 15, 1,139 feet per second; average, 1,120 feet per second.

The ventilating current at the time of the passage of the shock wave had in each case a velocity of about 2 feet per second in the same direction; deducting this, the net average velocity of the shock wave was therefore 1,118 feet per second, as shown by the combination of circuit breakers, automatic commutator, and chronograph.

The temperature of the air in the passageway during these tests averaged 42° F. A sound wave travels through air at this temperature at the rate of 1,096 feet per second.[a] A "shock" or impulse wave from the cannon, transmitted through the air, is equivalent to, or has practically the same longitudinal velocity as, a sound wave under the conditions through a tube or gallery. The difference, only 22 feet or 0.02 per cent, indicates the substantial accuracy of the pressure-velocity instrument system; on the other hand, dependence

[a] Landolt-Börnstein, Physikalisch-chemische Tabellen, 1905, p. —, results of Ciccone and Campanili.

on a single-stylus chronograph (time marker) and an intermediate automatic commutator which, under the arrangement of the instruments, did not act quickly enough for the higher velocities, was not satisfactory, as a failure of any one of the circuit breakers to operate prevents obtaining records beyond that point. Therefore, it has been decided that in future tests there is to be a chronograph with as many recording pens as there are circuit breakers, so that each may be

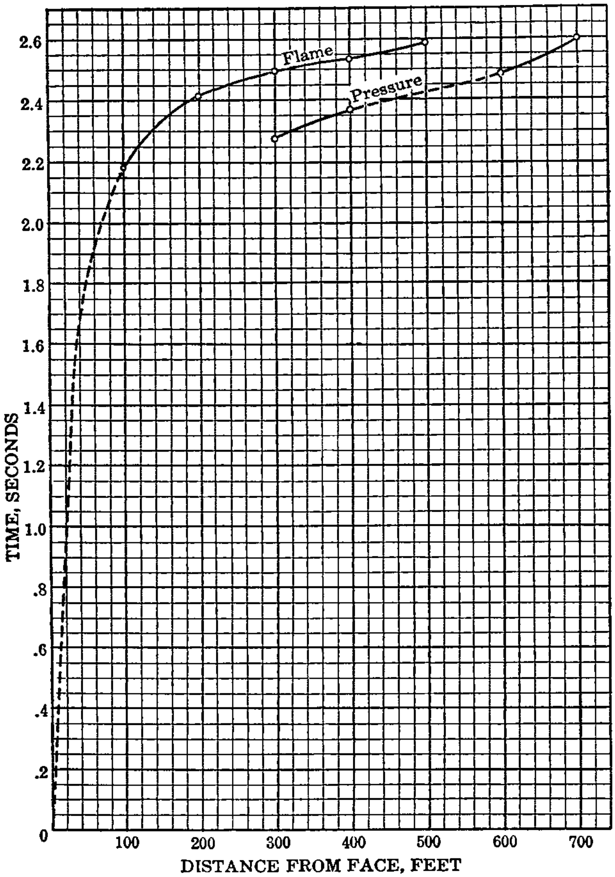


FIGURE 9.—Relative positions of flame and pressure wave, test 15.

independent in registration although marking on the same drum; the registration will then be referable to the same time intervals.

When a blown-out shot has been fired the shock wave raises the coal dust in the vicinity into the air, and the flame ignites the dust. At first it would seem there is merely quiet combustion, but if the coal dust is inflammable, pressure is gradually developed and the pressure waves start. In test 15 the period of developing pressure, including time of traversing the first 300 feet, occupied 2¼ seconds from the time of ignition. When the pressure wave reached the 300-foot point it was far behind the shock wave caused by the blown-out shot. The pressure-velocity curve obtained from the records of test 15 is shown in figure 9. Although the data are incomplete, sufficient details were obtained to make apparent the slow development of pressure and velocity to the 300-foot point, where the pressure wave started off at a higher rate but less than the velocity of a sound wave. At the 600-foot point the manometers indicated a slowing up between the stations at 600 feet (E 150) and 700 feet (E 50) from the origin. It is possible that the indicated decrease in velocity is due to the lag of the manometer at the 700-foot point. Much additional information from further experiments must be obtained before conclusions can be drawn as to the normal pressure-velocity curve resulting from uniform dust loading in a given size and shape of passageway, and other known controlling factors.

RECORDS OF FLAME VELOCITIES.

The data of indicated flame velocities in the first series of tests are more satisfactory than those of the pressure velocities. There are fewer difficulties with the flame circuit breakers than with the pressure circuit breakers, since there is only one flame record to be made; but there was difficulty with the automatic commutator and single-point chronograph, since failure of any breaker meant loss of all subsequent records.

Figure 10 shows the curve plotted from the flame-velocity records from tests 6, 7, 8, 12, and 15. These curves indicate that for the first 200 feet the velocity is relatively low, averaging less than 200 feet per second. In the case of explosions showing the least violence, the velocities did not materially increase with distance, though in test 8 the velocity reached 400 feet per second. This velocity was attained about 60 feet beyond the end of the coal-dust zone; but, as a large amount of coal dust would be carried forward by the wave itself, there would be no lack of fuel for considerable distance.

Test 15 was most complete and satisfactory, although unfortunately the velocity records were not obtained as far as the mouth of the mine. A feature of great interest in the flame-velocity curve (fig. 11) plotted from the record is the seeming attainment and passing of a maximum velocity between the points 350 and 400 feet from the origin. However, as there was only one registration beyond this apex, it would not be safe to assume that a normal flame-velocity curve drops after a maximum has been reached.

In figure 9 are shown the time intervals from the moment of ignition of the blown-out shot to the instant of passing the various stations of the flame and the pressure wave, respectively. The last two points on the pressure curve, corresponding to time ordinates 2.48 and 2.605, were obtained from the B. C. D. manometer record; the other points were obtained from the chronograph record. The curves in figure 9

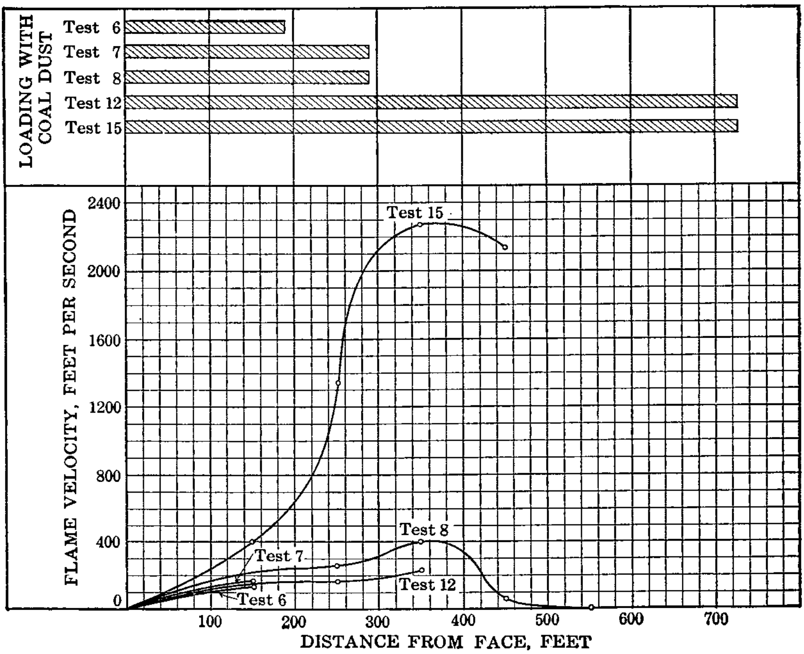


FIGURE 10.—Flame-velocity curves obtained in tests 6, 7, 8, 12, and 15.

show the relative position of the flame and that of the pressure wave, as obtained from the data from test 15. The horizontal distance

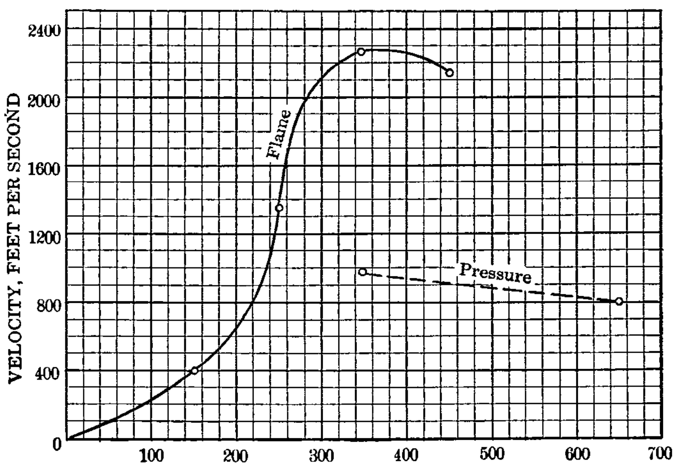


FIGURE 11.—Pressure-velocity and flame-velocity curves obtained in test 15.

between the two curves indicates the distance that the front of the pressure wave is in advance of the flame.

From the evidence of test 15 alone, the flame would appear to travel at the start more slowly than the front of the pressure wave; at 2.3 seconds after ignition the curves (fig. 9) indicate that the flame was 225 feet behind the front of the pressure wave; at 2.4 seconds after ignition it was 250 feet behind; at this point it began going faster than the pressure wave. The precision of these registrations is admitted to be somewhat uncertain. As stated, the pressure circuit breakers indicate only the front of the pressure wave; the flame circuit breakers do not act until the tin foil has melted, so that there is an appreciable lag, although this lag should be the same at each circuit breaker. From observations of issuing flame and records obtained from surface gallery explosions and from Taffanel's records of the Liévin station, it would seem that the flame is pointed, the point being in advance of the body of the flame, which fills the passage and melts the tin foil. If this is so, it is probable that the point of the flame may be much closer to the front of the pressure wave than is indicated by the curves of figure 9.

In future experiments the relation of the flame to the pressure wave will be made a special study. Manometers like those used by Taffanel will be tried. As the manometer drums carry sensitized paper the pressure curve will be photographed through the medium of a ray of light thrown on a mirror attached to a deflecting diaphragm, and simultaneously, through a glass-covered opening, the light from the flame will be photographed on the same paper, so that the exact time relation may be obtained.

RECORDS OF PRESSURES.

The B. C. D. manometers proved to be fairly satisfactory for the conditions to which they were subjected. Unfortunately, the motors supplied with the manometers were too small, with the result that in several tests no records were obtained. For the last test (test 15) stronger motors were installed. Although the instruments were designed with a view to reducing to a minimum the inertia of the moving parts, this inertia is large enough to introduce considerable errors in the records of pressures that rise with the rapidity of those resulting from explosions. In future tests it is planned to supplement the B. C. D. manometers with instruments of different design, in which the inertia of the moving parts will be much less.

As already commented, it is probable that the manometric curve (fig. 15) for station E 150 in test 1 does not show the maximum pressure. The highest point registered was 50 pounds, but it is quite possible that the peak of the curve was considerably higher. The same is true of both the manometric curves (fig. 27) in explosion 15, in which the highest point of the curve registered by the manometer at station E 150 was 103 pounds, and at station E 50, 60 pounds.

The B. C. D. pressure manometers do not register pressures below atmospheric pressure on the same instrument that records the positive pressures. In several of the experiments one of the manometers was arranged to record pressures below normal atmospheric pressure. In each case the instrument was placed in the station 50 feet from the entrance. In test 15 the maximum depression registered at this point was about 1.80 pounds, sustained for one-tenth of a second, the entire period of depression being three seconds.

MAXIMUM-PRESSURE GAGE RECORDS.

On account of imperfections in the copper cylinders of the maximum-pressure gages used in the later tests of the first series, the results obtained were not reliable. It is hoped that with improvements in making the cylinders the maximum-pressure gages will furnish as reliable a check on the records obtained with the recording manometers as that reported in the Liévin tests.

GAS SAMPLING.

The difficulties that were experienced in getting samples with the B. C. D. automatic samplers have been discussed in detail on page 38. No samples of afterdamp were obtained except those gotten by hand at a considerable interval after the explosion. In addition to the improvements planned on the B. C. D. instrument, it is proposed to employ other gas samplers arranged in groups of three at one station, to be automatically actuated by the flame so that three gas samples may be taken at predetermined intervals during and after the passage of the flame.

Two samples of afterdamp, gathered by men wearing breathing apparatus 15 minutes after explosion test 15, are of much interest. They were taken at points only 150 and 200 feet from the mouth of the main entry; consequently they were largely diluted by the air that entered immediately after the explosion. The most striking feature of the analyses (see page 113) is the high ratio of carbon monoxide to carbon dioxide (1:1.51 in the first instance and 1:1.36 in the second instance), which seems to indicate that at the time of explosion there was a great excess of carbon in the air.

VENTILATION.

In all of the experiments, except in test 8, there was employed a ventilating current with a velocity of about 100 linear feet per minute, the current traveling in the same direction as the explosion. Test 8 was made in still air. In other words, the explosion traversed the return-air passageway. In the next series of experiments it is planned to use ventilating currents of higher velocity and to duplicate certain explosions, except in one test to have the air travel with the explosion and in the other test against it.

HUMIDITY.

It happened that in the majority of the experiments the humidity of the air was high. This was especially the case in the public demonstration on October 30, 1911 (test 2). Therefore, it would appear from these tests that the humidity of the air itself has no appreciable effect upon a strong explosion. In almost all the experiments the floor was kept moist in order to prevent the dust of the track ballast from being brought into the air and affecting the explosion. The coal dust in all cases was dry and had been placed only a few hours previous to the experiment.

DESCRIPTION OF INSTRUMENTS FOR MEASUREMENT OF VELOCITY AND PRESSURE.

In order to devise means for the prevention of coal-dust explosions, as well as for the arrest of explosions that have started, a knowledge of the nature of such explosions and of the accompanying phenomena is necessary. It is essential to ascertain the physical laws governing the propagation of the explosions and the chemical processes that take place, as well as the means by which ignition of the dust is brought about. A study of the propagation of a coal-dust explosion requires the use of instruments for recording the pressures developed at various stages of the explosion, for recording the velocity of propagation of the explosion, and for taking samples of the gases produced by the explosion.

Instruments especially adapted for this purpose have been designed in England for the experiments of the British Coal Dust Commission at Altofts, and in France for the investigation at Liévin. Most of the instruments used in the preliminary experiments described in this report are the same as those used at Altofts and were furnished by the English manufacturers.

As the experiments at Altofts were made in a steel gallery above ground, recording instruments used could be mounted outside the gallery, no special precautions being necessary for their protection. The protection of instruments for recording the results of explosions in an underground gallery is more difficult. In the experimental mine of the Bureau of Mines, protection is afforded by rooms cut in the rib at intervals along the entry and closed by steel doors (Pl. V, *A*). The instruments connect with the entry through openings in the doors. A description of these instrument stations appears in a preceding section of this report.

PRESSURE RECORDERS.

Two types of instruments are used for the measurement of pressure, one to obtain a continuous record of the pressure and the other to record the maximum pressure.

B. C. D. MANOMETER.[a]

The B.C.D. manometer (Pl. IX, *A*, and fig. 12) is of the former type, and records the movement of a strong, tempered-steel, triangular spring (*s*, fig. 12) under the pressure of the explosion. The spring is clamped at its base; the force of the explosion acts vertically upward at its apex, which carries a fine steel point or scribing style. In this form of spring the maximum strain is the same at all cross sections, and the inertia is lessened, since the narrow light part of the spring moves most and the wide heavy part least.

The pressure is transmitted by an oil cushion to a cylindrical plunger (*p*, fig. 12), which can move freely in a vertical direction in an open cylinder. The oil keeps the plunger well lubricated, reduces

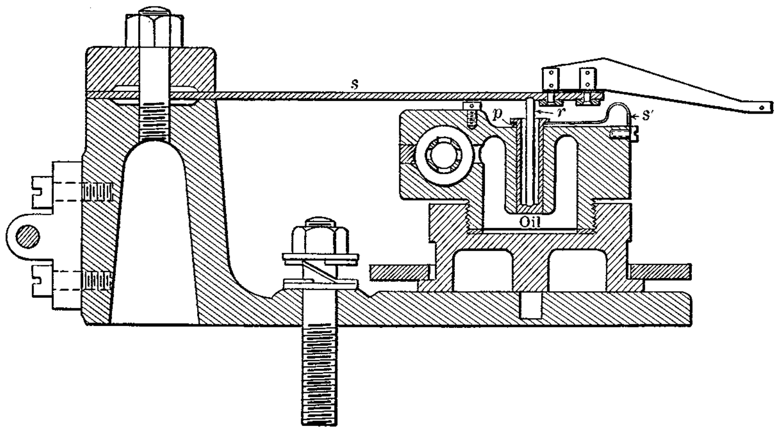


FIGURE 12.—Section of B. C. D. manometer.

leakage past it, and prevents the fine dust with which the compressed gases are charged from cutting or clogging the rubbing surfaces; the oil box also acts as a dash pot, damping any rapid vibrations. The plunger is hollow for the sake of lightness. It makes contact with the spring by means of a loose connecting rod (*r*, fig. 12), one end of which rests in a conical depression in the bottom of the plunger, the other end resting in a similar depression in the lower face of the triangular spring (*s*, fig. 12). A secondary weak spring (*s*′) acts upward on the plunger, holding the connecting rod in place when there is no pressure acting on the oil box. The scribing style on the end of the triangular spring (*s*) presses lightly against a smoked-paper band, which is lapped around a revolving drum. The drum is driven at a constant speed by an electric motor. After an experiment the smoked paper is removed and the surface fixed by immersion in a bath of transparent varnish.

[a] "B. C. D.," the distinguishing mark used for these instruments by the makers, refers to the British Coal Dust Commission, for whom they were designed.

The pressure of the explosion is transmitted from the mine entry to the manometer through a piece of heavy hose, as short in each case as conditions will permit, usually 1 foot to 2½ feet long.

In order to compare one pressure record with another record of the same explosion it is necessary to know the relative position of each manometer drum at the instant the explosion started, and the speed of revolution of each drum. Two Deprez indicators attached to each manometer are used for this purpose. The Deprez indicator is a small electromagnet that holds down, against the pull of a weak spring, a light aluminum style resting against the smoked surface of the manometer drum. As soon as the electric circuit is broken the style moves in a direction perpendicular to the direction of rotation of the drum.

An indicator on one manometer is connected in series with one on the next, and the circuit goes through a fine wire stretched in front of the igniting shot. At the instant this wire is broken by the shot, each style makes a mark on the smoked paper on its drum.

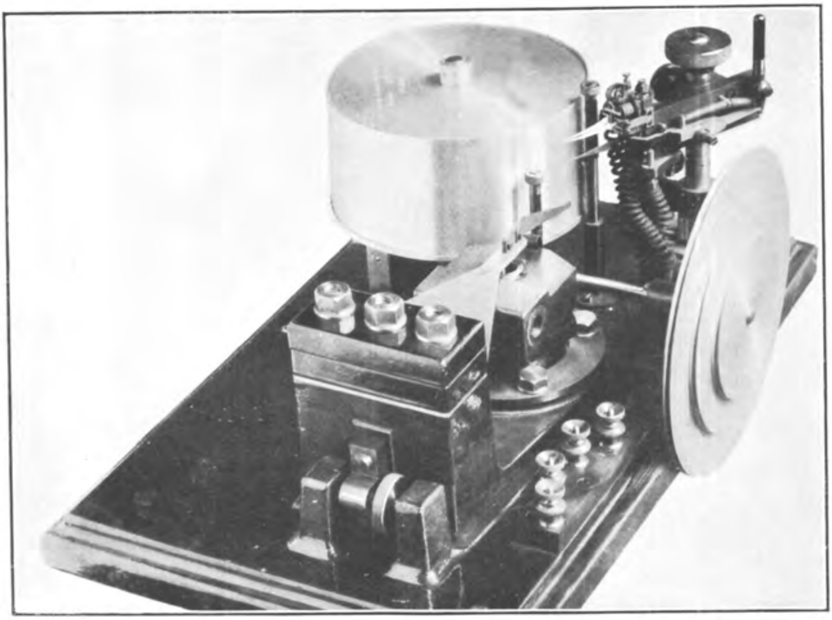
The second indicator on each manometer records the speed of revolution of the drum. These indicators are connected in series with each other and with the "tenth of a second time marker," known as the B. C. D. time marker.

B. C. D. TIME MARKER.

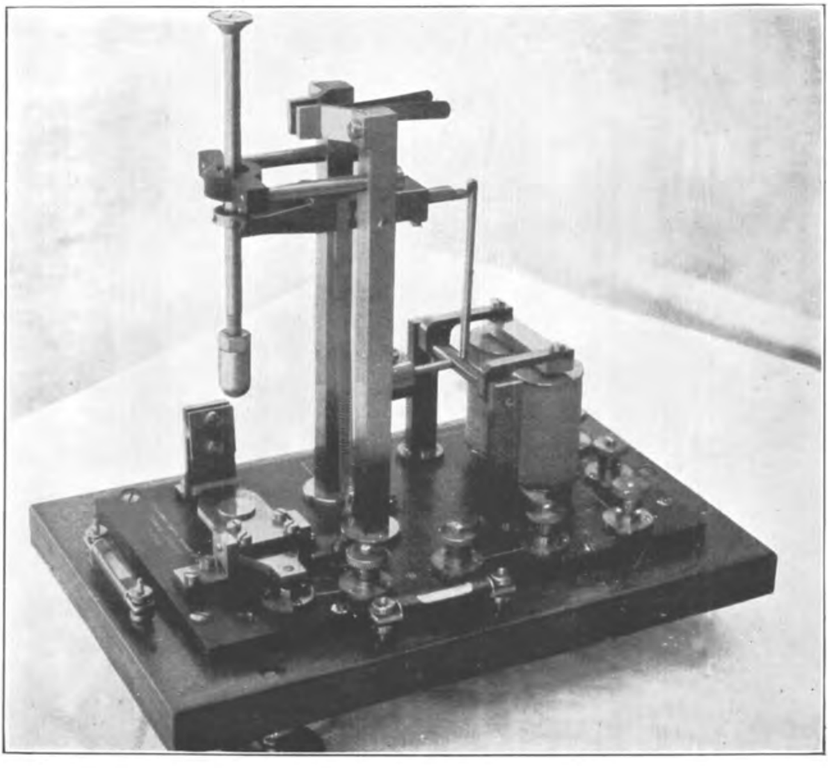
The B. C. D. time marker (Pl. IX, *B*) has a weight so arranged that when suspended at rest an electric current passes through it; when the weight falls, the circuit is broken. While the weight is falling, a circuit is again made, but is broken when the weight comes to rest. Consequently, when the time marker is connected in series with the Deprez indicators on the manometers, a break, a make, and a break are successively traced on the drums by the styles.

The space between the two breaks recorded on the drum is equivalent to the time required for the weight to fall from rest through the given distance. This distance, S, is calculated from the dynamic formula $S = \frac{1}{2}gt^2$, so as to represent a time interval, t, of just one-tenth of a second. The space between two breaks, instead of between a break and a make, is measured so as to eliminate any error from the lag of the indicator. This lag would, of course, be the same for two breaks, but might be different for a break and a make.

The two breaks in the circuit are obtained in the following manner: The weight rests freely on brass knife edges in a V support pivoted at the middle. When the weight is thus supported the circuit is complete and the current can pass through the electromagnets on the manometers. As soon as a catch is released a spring rotates the support from under the weight and the circuit is broken at the



A. B. C. D. PRESSURE MANOMETER.



B. B. C. D. TIME MARKER.

instant the weight begins to fall. The strength of the spring is such that the support is rotated well out of the way of the knife edges on the weight rod. While the weight is falling, the opposite end of the support flies up and closes the circuit again. As soon as the weight hits the platform at the bottom of its fall the circuit is again broken.

By means of suitable electrical connections, the catch is released by an electromagnet operated by the same switch that fires the igniting shot, so that the time interval recorded begins at the moment the explosion is started.

B. C. D. MEASURING APPARATUS.[a]

The smoked paper records, after being removed from the manometer and fixed in a bath, are placed on a special drum (Pl. VI, *B*) and are examined under a microscope. The circumference of the drum is graduated into millimeters, so that the distance between any two points on the chart can be measured by rotating the drum and bringing the points on the chart in turn under the cross hairs of the microscope. Since the $\frac{1}{10}$-second interval marked on the chart is always over 50 mm. long, 0.1 mm., which may be read on the chart, would correspond to one five-thousandth of a second.

By means of a micrometer screw with a divided head, the drum can be moved axially in the direction of motion of the pressure spring. By this means the pressure ordinates may be measured accurately to 0.01 mm.

The manometer springs are calibrated by applying known pressures to the manometer with a Schaeffer and Budenberg dead-weight pressure-gage tester and a standard gage.

SUCTION MANOMETER.

One of the three B. C. D. manometers used in this work is so made that it may be converted into a suction manometer; it was used as such during the tests of January and February, 1912. A much lighter spring is used for this purpose and is placed so that its zero position is higher on the drum than that of the pressure springs, thus allowing room for a downward deflection. The plunger, by means of a light framework, makes contact upon the upper face of the spring. Any suction applied to the manometer pulls the plunger downward, deflecting the spring in this direction. The spring is calibrated by means of a vacuum pump and a mercury manometer.

MAXIMUM-PRESSURE GAGES.

The maximum-pressure gages are of the "crusher" type used in ordnance work to measure the pressures in the chambers of large guns, and are similar to the gages used by Taffanel.

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[a] See Pl. VI, *B*.

A cross section of one of the gages is shown in figure 13.

The value of the maximum pressure is determined from the shortening of a small copper cylinder under pressure. A light hollow plunger (*p*) fits into one end of a cylinder (*b*), the other end of which is open to the mine entry. Grooves cut around the outside of the plunger, or piston, are filled with heavy grease or tallow to prevent corrosion and reduce leakage past the plunger. The copper cylinder, which is about 0.063 inch in diameter and 0.1023 inch long, is set on end in the bottom of the plunger, and a cap (*c*) with a projecting pin (*a*) in the center is screwed down against it.

The length of the copper cylinder is measured with a micrometer caliper before and after the test, and the pressure is determined from the amount of shortening of the cylinder.

Eight of these gages and a large number of copper cylinders were made at the naval gun factory, Washington, D. C. The calibration curve for the copper disks was furnished by the maker.

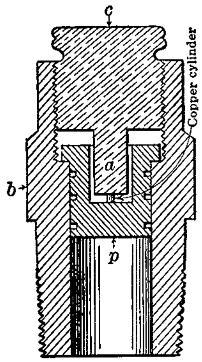

FIGURE 13.—Cross section of maximum-pressure gage.

VELOCITY RECORDERS.

The method of measuring the velocity of the pressure wave is to allow it to break a series of electrical circuits, at regular intervals along the mine. The breaking of each circuit is recorded by the release of an electromagnetic pen which makes a line on a suitable surface traveling at a known speed.

B. C. D. PRESSURE CIRCUIT BREAKER.

The breaking of the circuits at the various points is accomplished by means of the B. C. D. circuit breakers, which are adjusted so as to operate circuit only when a definite pressure has been exceeded. The breaker (Pl. VI, *A*) has a tube opening at one end into the mine entry and connected at the other end to a cylinder containing a plunger, which is held down by a lever and heavy spring. By varying the tension of the spring the pressure required to lift the plunger may be fixed at any value from 2 to 20 pounds per square inch. A pin projects from the side of the plunger, and when set this pin rests on two aluminum plates completing an electric circuit between them. A small spring acts on the outer end of this pin and tends to rotate the plunger; rotation is prevented by the aluminum plates, their shape being such that the downward pressure of the plunger holds the pin on both of them. As soon as the explosion raises the plunger, the contact is broken and the small spring pulls the pin to one side, thus preventing any remake of the circuit when the plunger falls again.

AUTOMATIC COMMUTATOR.

Any variation in the lag of the electromagnetic pens used to record the breaks of the circuit breakers, although short in itself, might constitute a comparatively large percentage error since the time interval to be measured is so very short.

Such an error is avoided in this apparatus by using an instrument termed an "automatic commutator" (Pl. VII, *B*, and fig. 14), which enables each successive break to be recorded by the same electromagnetic pen. This instrument is used in connection with the recording instrument (chronograph) described on page 62. The

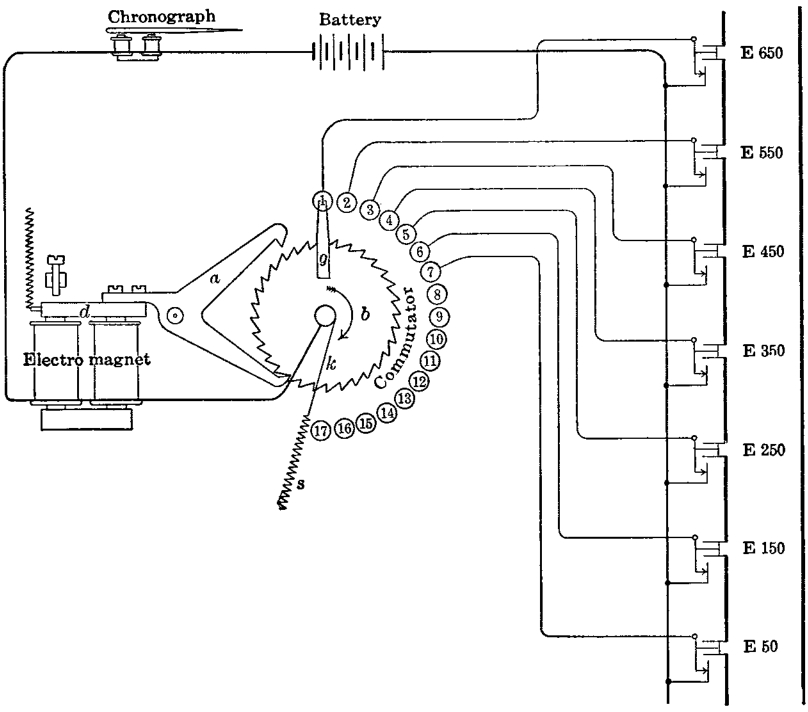

FIGURE 14.—Wiring diagram of automatic commutator.

current from the battery (fig. 14) goes through the electromagnet on the chronograph so that its armature is attracted, and then through the electromagnet of the commutator to the brush (*g*, fig. 14). The other terminal of the battery is connected to one terminal of each of the circuit breakers (at E 650, E 550, etc., fig. 14). The second terminals of the circuit breakers, in the order in which the explosion reaches them, are connected by separate wires to the studs on the commutator (1, 2, 3, etc., fig. 14).

Assume that the brush *g* rests on stud 1 (the position it occupies before the explosion); the current then flows in order through the electromagnet on the chronograph, the commutator electromagnet, the brush *g* circuit breaker 1 (as at E 650), and back to the battery. If the explosion breaks the circuit at circuit breaker 1 (as at E 650) the chronograph electromagnet releases its armature and the pen makes a mark on the moving surface; at the same time the armature *d* of the commutator electromagnet is released and the anchor escapement *a* attached to the armature is moved. This allows the spring *s* to pull the scape-wheel *b* around by the cord *k*, which is wound on a drum, attached to the axis of the scape-wheel. The brush then moves part way to stud 2; the current immediately begins to flow through circuit breaker 2 (as at E 550), the chronograph electromagnet, and the commutator electromagnet; the armatures of both magnets are again attracted; and then the pen on the chronograph is moved back to its former position. On the commutator, the armature *d* and the escapement *a* move back to their former position and the brush *g* moves a little farther on to stud 2. When the explosion operates circuit breaker 2 (as at E 550) the brush moves to stud 3, the same cycle being repeated, and so on, for as many points as may be fixed, all the breaks in the circuits being recorded by the one pen on the chronograph so long as they occur in the proper order. It will be readily seen, however, that if any one circuit breaker fails to operate properly, no records will be obtained at the circuit breakers following, since the armature on the automatic commutator will not be released, and consequently the brush will not be free to move to the next stud.

CHRONOGRAPH.

The laboratory chronograph (Pl. VI, *B*) used in connection with the automatic commutator and circuit breakers traces a record in ink on a long riband of paper. It comprises three electromagnets to the armature of each of which is attached a brass recording pen that moves with the armature when the electric circuit is made or broken. The pens rest lightly on the strip of paper which is drawn along at a uniform rate by an electric motor. One of the electromagnets is connected in series with a storage battery and a "contact clock" which breaks the circuit every half second, thus giving the speed at which the paper travels. A second electromagnet is connected as described above, and its pen records the various breaks in circuit due to the pressure wave of the explosion. From the breaks the velocity of the wave may be determined. The third pen is used to record the travel of the flame during an explosion.

FLAME CIRCUIT BREAKERS.

The method of obtaining the velocity of the flame is the same as that for obtaining the velocity of the pressure wave, except that a different form of circuit breaker is used. The breaker must be sensitive to heat but not affected by pressure.

The first form of flame circuit breaker tried was simply a detonator, such as is used for "setting off" dynamite, placed in a wooden block, so that its open end would be exposed to flame passing through the entry and having a small wire wrapped a couple of times around it. The ends of this wire were carried back through separate holes in the wooden block and connected in the automatic commutator circuit. Each detonator was made extremely sensitive to heat by coating the inside and the open end of the brass capsule with silver carbide, which explodes at a lower temperature than the fulminate. This carbide coating was suggested by W. O. Snelling, chemist, formerly connected with the bureau.

In a slight modification of this form of circuit breaker the silver carbide was placed on a match stick instead of directly upon the brass cap. The advantage of the modification was that the match stick could be put in the detonating cap a few minutes before the explosion and not have as much time to collect moisture from the damp mine air as did the cap, which had to be in place two or three hours earlier.

The detonator form of flame circuit breakers, however, was not entirely satisfactory. It was finally replaced by the tin-foil circuit breaker, which consists simply of a small strip of tin foil that is fused by the heat. Each strip is about one-fourth of an inch wide and 1½ inches long, and is placed in a groove (about three-sixteenths of an inch deep) in a wooden block, for protection against mechanical injury. Wires fastened to either end of the strip are carried back through the block and make connection with the instruments in a manner similar to that described for the pressure circuit breakers, except that circuit breaker 1 is connected to stud 2 (fig. 14) on the automatic commutator. The first point on the commutator is connected to a fine wire stretched across the entry in front of the igniting shot. The wire is similar to the "ignition wire" connected to one indicator of the B. C. D. manometers.

The pressure circuit breakers and flame circuit breakers, in the series of tests here described, were placed at intervals of 100 feet along the main entry of the mine in the stations already described, the first one being about 100 feet from the igniting shot.

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B. C. D. AUTOMATIC GAS SAMPLER.

The apparatus used to obtain a sample of gas during the explosion is of the B. C. D. automatic type (Pl. VII, *A*), and is designed to meet the following conditions:

(1) The exact moment at which the sample is taken with reference to the explosion must be known and must be capable of alteration at will.

(2) There must be no air in any of the connecting pipe between the sampling bottle and the mine entry.

(3) The time during which the sample is being taken must be very short if a sample from only one stage of the explosion is desired.

A steel sampling bottle is connected to a short pipe that just reaches into the mine entry. The inner end of this pipe is closed by a glass cap and the whole (bottle and pipe) is exhausted to a pressure of about 3 mm. of mercury.

A circuit maker, which is similar to the B. C. D. circuit breaker except that its operation closes an electric circuit instead of opening one, is placed at any desired location in the mine. The pressure wave causes the circuit maker to close an electric circuit through a fine fuse wire that holds back a hammer over the glass cap of the sampler. The current fuses this wire and allows the spring to pull down the hammer and break the cap; then gas rushes through the pipe and into the exhausted bottle.

The current also passes through an electromagnet in parallel with the fuse wire, so that at the same time the wire is fused the armature of the magnet is pulled down and releases a trigger which in turn allows a small weight to fall. Gas enters the bottle during the time this weight is falling. To the weight is attached a cord which, after the weight has fallen a short distance, suddenly jerks a pin that releases a heavy weight. This weight, by means of a cord and pulley, turns a valve that closes the bottle. The length of time that the bottle remains open is regulated by the length of the cord attached to the small weight.

The instant of taking the gas sample is fixed by the location of the circuit maker. Thus, if the circuit maker is located alongside of the gas sampler, the time of sampling will coincide with the passage of the front of the pressure wave. By placing the circuit maker between the gas sampler and the point of ignition, the gas sample may be taken in advance of the pressure wave.

ARRANGEMENT OF APPARATUS.

Of the above instruments, the pressure-measuring instruments, the circuit breakers, and the gas sampler and its circuit maker are placed in the various stations in the mine. The tenth of a second time marker, the two automatic commutators, the chronograph, the half-second clock, the batteries, and the operating switches are placed in the observation room. (See Pl. VI, *B*.)

The connections necessary for operating these instruments are made through two cables which run from the observatory to all the stations in the mine (see fig. 8) through a pipe embedded in the rib and faced with concrete (see Pls. II, *A*, V, *A*, VI, *A*, VII, *A*). The smaller cable contains three wires and supplies electrical power at 110 volts for the manometer motors, the gas sampler, and lights in the mine. The larger cable contains 1 No. 10 wire and 30 No. 16 wires (B. & S. gage) and carries low-voltage current from the storage batteries only. This cable supplies the two shot-firing lines, the tenth of a second and the ignition lines to the manometers, and the circuit breaker lines, besides a number of spare wires for special use. The No. 10 wire is used as a common return to the observation room for all circuits.

DETAILS OF EXPLOSION TESTS.

The most important details of the 15 experimental-mine explosion tests that constituted the major part of the investigation here reported are given below in condensed form.

TEST 1.

Date.—October 24, 1911.

Purpose.—To determine the possibility of obtaining a large coal-dust explosion at the mine and to obtain records of the resulting pressures and velocities.

Point of origin of explosion.—Face of main entry, 722 feet from mouth.

Method of ignition.—Blown-out shot from a 1½-inch pipe in the coal.

Charge.—Two pounds of FFF black blasting powder, tamped with 2½ inches of damp clay.

COAL DUST.

Source.—Dust was ground from bituminous coal from the Pittsburgh bed at Oak mine, near Pittsburgh.

Size.—Over 98 per cent passed through a 100-mesh sieve.

Analysis.—

Moisture	1.94
Volatile matter	35.11
Fixed carbon	57.73
Ash	5.22
	100.00
Sulphur	1.25

Zone.—Main entry, E 722[a] to E 300, or 422 feet; gallery slant: Some old coal dust remaining on side shelves from previous gallery tests.

Position.—E 722 to E 702 on bench just below the hole containing igniting charge; E 712 to E 472 on temporary side shelves; E 472 to E 300 on transverse "book" shelves.

Quantity.—500 pounds of coal dust, or a little more than 1.18 pounds per linear foot of entry. The load was equivalent to 0.315 ounce per cubic foot of space or 315 grams per cubic meter.

Inert zone.—E 300 to opening, no coal-dust load; air course, no coal-dust load.

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[a] An expression consisting of a number preceded by the letter E refers to a point in the main entry distant from the end of the buttress wall at the mouth of the entry by the number of feet indicated.

VENTILATION AND HUMIDITY READINGS.

Ventilation.—5,000 cubic feet of air moving through last cut-through.

Humidity.—

Station.	Wet bulb.	Dry bulb.	Humidity.
	°F.	*°F.*	*Per cent.*
Outside mine.....	44	52	52
Third cut-through .	56	57½	91

Barometer.—28.88 inches.

INSTRUMENTS AND RECORDS.

MANOMETERS.

Location.—Manometer A at station E 150; manometer B at station E 50.

Spring.—Thirty-pound springs were used in both manometers.

Records.—See figure 15.

PRESSURE CIRCUIT BREAKERS.

Location.—At stations E 150 and E 50, 100.25 feet apart.

Recorded time between stations.—0.0513 second.

Recorded velocity between stations.—1,954 feet per second.

Adjustment.—Could be operated by a pressure of 5 pounds.

OUTSIDE MANIFESTATIONS.

Length of flame.—Huge masses of flame burst out of the openings. Flame from the main opening estimated to have extended 200 to 300 feet (fig. 16).

Violence of explosion.—The roof of the fan drift was blown off and landed on the tram-road track, 25 feet distant. The 2-inch plank stopping at the end of the steel gallery was blown out. The sandbags on the explosion-door section were thrown high in the air, and the board framework beneath them was destroyed.

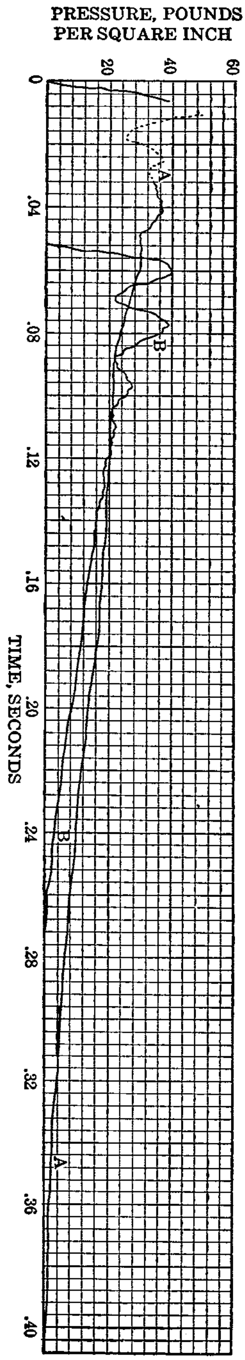


FIGURE 15.—Manometric curves, test 1, pressure above atmospheric. A, curve obtained at station E 150; B, curve obtained at station E 50.

A car that stood 50 feet from the opening and was filled with small boards was blown over the side of the slate dump and fell across a wire fence 90 feet from its first position.

A 5-ton gasoline locomotive that had stood just beyond the car was moved 15 feet, and its top plate, pivoting on the rear bolts, was bent through 180°. A car dump which had been at the end of the slate dump was blown 30 feet over the west side of the slate dump.

A steel-plate door weighing about 60 pounds was blown from a point a short distance within the main entry over the dump and was half buried in the ground in the valley beyond the dump, 200 feet from the opening.

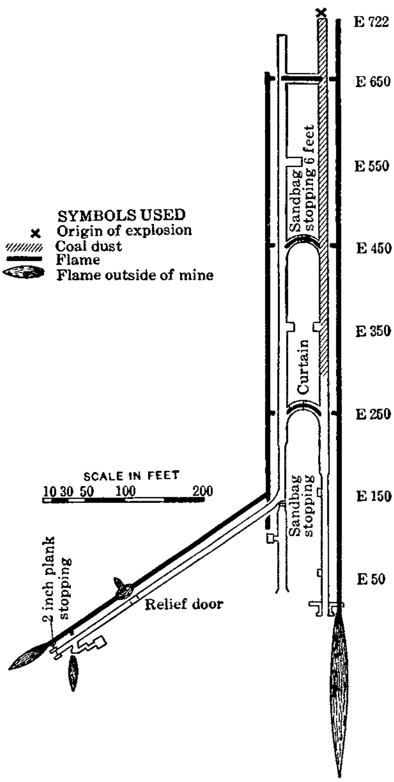


FIGURE 16.—Test 1, extent of flame and conditions of test.

INSIDE OBSERVATIONS.

Violence.—The concrete wall over the top of the steel-plate door at station E 50 was cracked through into the station. The concrete lining was cracked along the springing line on both sides of the entry for 50 feet inby E 50. The concrete arch was cracked from side to side at three points, 18, 30, and 54 feet from the opening. All the steel rails and timbers which had held up the roof at the intersection of the first cut-through and the main entry were thrown down. Some of the timbers were carried out the entry and some through the air course, but the rails had simply dropped out of place. The sandbag stopping in the second cut-through was piled against the inby rib. Some bags were blown into the entry and some into the air course. All the posts and shelves outby the last or inner cut-through had been blown down with the exception of three posts on the east side of the entry. The stopping in the air course outby the intersection with the gallery slant had been blown down and some of the bags had been carried through the air course to the opening 117 feet distant. The concrete arch in the air course just inby the stopping was cracked from side to side, as was also the arch of the gallery slant at the intersection.

Cracks in the gallery concrete along the springing line extended for 54 feet outby the intersection with the air course.

Coked dust.—Very little coked dust was noted. There was a deposit on the north rib of the first cut-through near the air course on exposures facing the air course. Some coked dust was deposited on the inby side of the cap of the first timber set in the air course outby the first cut-through.

Soot filaments.—In the main entry inby the last cut-through were found many soot filaments hanging from the roof and ledges on the ribs. Some of these were 2 inches in length. A sample of these filaments was analyzed with the following result:

Moisture	1.51
Volatile matter	27.15
Fixed carbon	36.33
Ash	35.01
	100.00

[Volatile matter : fixed carbon :: 42.77 : 57.23.]

It is possible that the high ash content was due to impurities having gotten into the sample when the soot filaments were scraped off the slate roof.

NOTES.

It had been planned to cause this explosion by firing two shots, one from the pipe embedded in the face of the entry and another immediately afterwards from a cannon 18 feet from the face. It was thought that the first shot would blow up a cloud of coal dust and the second shot would ignite this cloud. However, the first shot ignited the dust and caused the explosion. The explosion disarranged the firing wires for the cannon and its charge was not fired.

TEST 2.

Date.—October 30, 1911.

Purpose.—Public exhibition of the explosibility of coal dust and a determination of the resulting pressures and velocities.

Witnesses.—Representative mining men from all parts of the United States. Attendance, about 1,500 persons. Over 1,200 persons passed through the mine and inspected the coal-dust distribution and the position of the shot.

Point of origin of explosion.—Face of main entry, E 725. (The face had been advanced 3 feet since the first explosion test.)

Method of ignition.—Four blown-out shots; three from 1½-inch pipes in the coal and one from a 1½-inch pipe lying on the bottom.

Charge.—A total of 9¼ pounds of FFF black blasting powder in four holes; each charge tamped with 4 inches of damp clay stemming.

COAL DUST.

Source.—The coal dust was ground from bituminous coal from the Pittsburgh bed at Oak mine, near Pittsburgh.

Size.—Over 98 per cent passed through a 100-mesh sieve.

Analysis.—

Moisture	1.94
Volatile matter	35.11
Fixed carbon	57.73
Ash	5.22
	100.00
Sulphur	1.25

Zone.—Main entry, 691 feet from face; first cut-through, air course between first cut-through and gallery slant, and gallery slant, 481 feet. Total length of coal-dust zone 1,172 feet.

Position.—E 725 to E 709 on bench below the hole containing the igniting charge; E 712 to E 34 on temporary side shelves, and on 12 "book" shelves placed at intervals; first cut-through on four transverse "book" shelves; air course and slant on temporary side shelves.

Quantity.—Six hundred and twenty-seven pounds in the main entry (average cross section 60 feet), or 0.907 pound per linear foot, which is equivalent to 0.242 ounce per cubic foot (242 grams per cubic meter); 225 pounds in the branch from the entry to the gallery slant (average cross section 48 feet), or 0.468 pound per linear foot, which is equivalent to 0.156 ounce per cubic foot (156 grams per cubic meter).

Inert zones.—No coal-dust loading in the air course inby the first cut-through or outby the stopping at the gallery slant.

VENTILATION AND HUMIDITY READINGS.

Ventilation.—The fan was furnishing to the gallery slant 10,600 cubic feet of air, and 5,000 cubic feet was passing through the last cut-through.

Humidity.—About 11.30 a. m. a drizzling rain began which continued the rest of the day, so that the air throughout the mine was probably in a nearly saturated condition at the time of the explosion.

ATTEMPTS TO FIRE IGNITING SHOT.

After all the visitors who wished to inspect the mine had done so, the shot-firing lines were connected to the lead wires of the electric igniters in the charge, and after all persons had withdrawn to positions of safety, and the prearranged warning signals given, the firing button was pressed, closing the circuit. No explosion resulted. An inspection of the shot-firing lines in the mine disclosed a short circuit in the lines where they had been trampled by some of the visitors. A second trial resulted in a second failure. As the place of short-circuiting was not found by a second inspection, an entire new shot-firing line was installed. It was evening before the warning signals were given for a third time, when the button was pressed and an explosion resulted.

INSTRUMENTS AND RECORDS.

MANOMETERS.

Location.—Manometer A at station E 150; manometer B at station E 50.

Spring.—Thirty-pound springs were used in both manometers.

Records.—As the motors which drive the drums of the recording manometers did not run during the explosion, the records showed the maximum pressures only. Maximum pressure of manometer A, 26.5 pounds; manometer B, 21.3 pounds.

PRESSURE CIRCUIT BREAKERS.

Pressure circuit breakers were installed at station E 150 and station E 50.

Records.—No velocity records were obtained. When new shot-firing wires were installed after the second failure to obtain the explosion, the batteries used to operate the recording apparatus were disconnected from the apparatus and connected to the shot-firing line.

OUTSIDE MANIFESTATIONS.

LENGTH OF FLAME.

The flame burst out of all openings almost simultaneously and seemed to fill the valley from the main opening to the opposite hill (fig. 17). It was estimated that the flame from the main opening extended horizontally nearly 500 feet, and from 200 to 300 feet vertically. The vertical estimate is probably much too great, the glare on the clouds making the height seem greater than it really was. A tree 153 feet from the main opening was ignited at a point 46 feet above the level of the ground at the mine opening.

INDICATIONS OF VIOLENCE.

Before the explosion a mine car containing several hundred pounds of material had been on the mine track in the line of the entry 40 feet from the opening. Twenty-five feet beyond the car mentioned had stood a car loaded with coal, the total weight of which was about 2 tons. The partly filled car was hurled over the loaded one and thrown a distance of 184 feet into the ravine beyond the dump. It bounded four times after the first landing and came to rest at a point 45 feet beyond the first landing place; the total travel, measured horizontally, was, therefore, 229 feet. The loaded car first mentioned, even with the brakes set, was driven along the track and finally derailed 70 feet beyond its original position. The hill opposite the mine was strewn with pieces of shelving and posts (Pl. V, *B*). Posts 5 to 6 feet long and 6 inches in diameter were found 413, 354, and 250 feet from the mine opening.

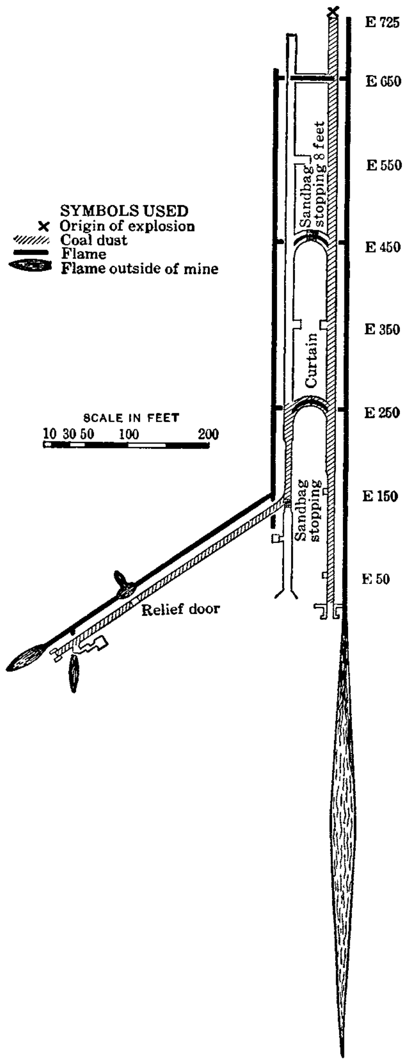


FIGURE 17.—Test 2, extent of flame and conditions of test.

A sandbag from the sandbag stopping in the air course at the intersection of the air course and gallery slant was found 45 feet from the air-course opening. Many other bags were found between this point and the opening; many of them had been torn and the sand spilled out. The sandbag farthest from the explosion-door section that was blown to the north was found 115 feet distant. Many bags were found scattered between this point and the explosion-door section. A considerable number of the bags were blown high in the air and a rain of sand resulted from their becoming broken and torn. One of the bags was caught in a tree near the explosion-door section at a height of 72 feet above its original position.

The "danger" signboard nailed on the cap at the air-course opening was blown off and was found 140 feet to the northeast. A piece of corrugated iron 2 feet wide and 7 feet long, which had been placed over the bags at the explosion-door section, was found 110 feet to the north. A second sheet of corrugated iron from the explosion-door section was found 260 feet to the northeast. A telephone pole 5 inches in diameter, which stood northeast of the tool house, was struck by a flying timber from the fan drift and was broken square off at a point 4 feet 9 inches from the ground. A second piece of the fan drift was found 100 feet northeast of its original position. Two windows on the south side of the tool house fell out toward the fan drift; this was no doubt due to a suction following the pressure wave of the explosion. Two lights in a window on the south side of the blacksmith shop were broken. The 1-inch board door and stopping at the end of the steel gallery was blown into small pieces and scattered over the dirt backstop. Flame also issued from the end of this gallery. Many sandbags from the explosion-door section fell to the south of the gallery, some as far as 100 feet up the hill. One bag became caught on a limb of a tree, 42 feet from the ground and 110 feet from the explosion-door section. A piece of corrugated iron was found on the upper side of a fence at a point 110 feet south from its original position. Many pieces of board were found in this field, some as far distant as 235 feet from their positions before the explosion.

INSIDE INDICATIONS OF VIOLENCE.

The action of great force was indicated in the concrete section of the main entry by numerous fractures of the concrete, particularly along the springing lines, and by the exposure and bending of many of the vertical reinforcing rods. The concrete arch had manifestly been lifted by the explosion, thus causing the vertical reinforcing rods to be thrown in tension. The rods tended to become straight where they curved around the arch at the springing line, and this tendency caused the breaking out of the concrete between the rods and the face of the concrete. A crack in the concrete at the springing line on the east side of the entry extended from a point 44 feet from the opening to a point 118 feet inby. On the west side the springing-line crack extended 44 feet to a point 117 feet inby. A large transverse crack (Pl. VI, *C*) was opened in the concrete arch at this point; for some distance inby this point the arch seemed to have been lifted bodily out of its place, and at this point it did not return to its former position but still remained 11 inches higher up. When the concrete lining was originally put in at this point a fall of roof occurred, and after the concrete lining had been put in, loose dirt was tamped into the hole in order to fill it as completely as possible; later the material settled, as there probably was a cavity above the concrete at this point. Practically all of the posts of the coal-dust shelving sets, from the concrete section in to E 612, were blown out. Inby this point the shelving sets seemed to have been merely upset. There had been a 7-foot sandbag stopping in the second cut-through. Practically all of the stopping bags were moved out of place; most of them were thrown against the inby rib, and some were scattered out into the entry and air course. The inby rib was coated with a layer of sand from the broken bags.

The center hole at the face was enlarged or "cratered" for several feet. The west shot merely "cratered" the front of the hole slightly, while the east shot cracked the coal vertically. The hole from the center shot was partly filled with dirt and broken pieces of wood which seemed to have been blown back into the hole by an air movement rushing back toward the face to fill the vacuum following the pressure wave of the explosion.

There had been a sandbag stopping across the air course just outby its intersection with the gallery slant. This was thrown down and the bags scattered along the air course to a point 55 feet outside of the opening. After the explosion the inrushing air carried inby some of the sandbags to the intersection with the gallery slant and some were thrown by the blast into the gallery slant to points 15 to 54 feet from the intersection.

The concrete pillar at the intersection of the two entries was cracked horizontally about 3½ feet from the bottom and while the upper half was raised by the pressure of the explosion, a piece of brattice cloth and a stick were caught in the crack when the concrete descended (Pl. VIII, *A*). The wooden doors in the air course were blown open and the hinge posts moved outby 3 to 4 inches. The lifting of the arch of the concrete section of the gallery slant caused longitudinal cracks along the springing lines almost the entire length of the entry. There were numerous exposures of the vertical reinforcement near the springing line, and in some cases the short diagonal braces from the crossbars to the posts of the temporary timber sets behind the concrete lining were exposed.

At G 168 [a] one of the vertical reinforcement rods was exposed for 3½ feet and the middle portion was bent 7 inches outby the original position. At G 164 [b] the roof in rising pulled the reinforcing rod up and when it settled again the rod became buckled (Pl. VIII, *B*); measurements of the buckled portion indicated that the roof had lifted 1 foot. The cover at this point was 8 feet. At G 161 [c] the concrete was cracked across the arch. The roof seemed to have settled slightly inby its original position.

COKE AND COKED DUST.

There were coke deposits on the inby corner of the entry and second cut-through and some coked dust on the west rib opposite

[a] One hundred and sixty-eight feet from outer end of iron gallery or 26 feet from mouth of gallery slant.
[b] One hundred and sixty-four feet from outer end of iron gallery or 22 feet from mouth of gallery slant.
[c] One hundred and sixty-one feet from outer end of iron gallery or 19 feet from mouth of gallery slant.

the second cut-through. At E 560 there were coked-dust deposits on the outby exposures of both the east and the west ribs, also in the inby cracks on the entry rib near the third cut-through. At E 635 on a shelving post still standing there was a deposit of coked dust on the inby side.

In the third cut-through the coal on each rib was blistered very badly (Pl. X). Coked-dust deposits began to appear about 20 feet from the entry in going toward the air course on the inby side of the cut-through on the exposures facing the air course and increased in amount toward the air course. Practically all coked dust on the outby side of the cut-through was on the exposures facing the entry.

At A 654 [a] there were heavy deposits of coked dust in the crevices at the corner of the cut-through.

Twenty feet inby the cut-through on the west side of the air course were deposits of coked dust on the outby exposures and coke bubbles along the bedding planes of the coal (Pl. XI). This coking effect has been termed "coke in situ."

There were frequent deposits of coked dust (Pl. XII, *A*) on both sides of the air course from the third cut-through to the second cut-through, principally on the outby exposures. From the second cut-through to the first the deposits were smaller and less frequent.

On the north rib of the blind cut-through at A 550 near the corner of the air course the rib was considerably blistered, and particles of coke were formed in place, grouped along the bedding planes of the coal bed.

SOOT COATING.

In the entry inby the third cut-through, the walls, roof, and floor were coated with soot, and threads or filaments of soot up to several inches in length were hanging from the roof (Pl. XII, *B*). The unburned hydrocarbons were seemingly deposited from the quiet atmosphere after the explosion, the ventilation not being reestablished until the following day. The analysis of the hanging filaments was as follows:

Moisture	2. 25
Volatile matter	41. 48
Fixed carbon	49. 60
Ash	6. 67
	100. 00

[Volatile matter : fixed carbon :: 45.54 : 54.46.]

The ash content was slightly higher than the ash content of the original dust, but the percentage of volatile matter in the ratio of volatile matter to fixed carbon increased considerably.

[a] A point in the air course nearly opposite E 644.

ANALYSES OF SAMPLES.

Samples of coked dust, blistered coal, stalactitic carbon, and road dust were obtained and analyzed after the explosion.

The results of a proximate analysis of a combined sample of blistered coal from the west rib of the air course and the north rib of the last cut-through are given below. For purposes of comparison the results of an analysis of a representative sample of the unaltered coal are given also.

Results of analyses of blistered and of unaltered coal.

Constituent.	Blistered coal.	Unaltered coal.
	Per cent.	*Per cent.*
Moisture	1.64	2.73
Volatile matter	34.56	36.03
Fixed carbon	60.49	54.98
Ash	3.31	6.26
Total	100.00	100.00

[Proportion for blistered coal—Volatile matter : fixed carbon :: 36.36 : 63.64; proportion for unaltered coal—Volatile matter : fixed carbon :: 39.59 : 60.41.]

A comparison shows that the percentage of volatile matter as compared with fixed carbon is less in the blistered coal than in the unaltered coal. The low ash content of the blistered coal undoubtedly is not significant of change. By accident the layer of coal had a much lower content than normal.

Two other samples of blistered coal were taken in the third cut-through. One was taken by cutting off as thin a slice as possible from the blister; the other represented a second thin layer beneath the first. It was thought that the analysis of the first sample, because of the blistering that caused the curved surfaces on the face of the coal, might show different results than did the analysis of the unaltered coal. The results of both analyses were as follows:

Results of analyses of two layers of blistered coal.

Constituent.	First layer.	Second layer.
Moisture	1.82	1.75
Volatile matter	36.17	37.83
Fixed carbon	55.45	57.25
Ash	6.56	3.17
Total	100.00	100.00

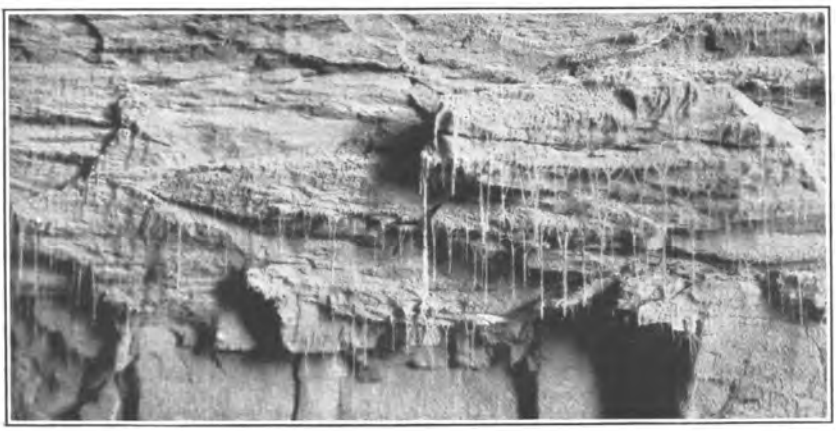
[Proportion for first layer—Volatile matter : fixed carbon :: 39.48 : 60.52; proportion for second layer—Volatile matter : fixed carbon :: 39.79 : 60.21.]

BLISTERED COAL RIB, TEST 2.

Note rounded faces where the outer shell of soot-coated coal spalled off after cooling.

COKE BUBBLES FORMED ALONG BEDDING PLANES OF COAL TEST 2.

A. COKED DUST, TEST 2.



B. COATING AND FILAMENTS OF SOOT, TEST 2.

The results of the analyses show practically no change in composition as compared with the results of analysis of unaltered coal. The low percentage of ash shown by the second analysis is not significant on account of the small size of the sample.

The bright conchoidal surfaces of a blister were exposed when a thin scale dropped from the blister. As both the scale and the blistered coal were included in the above analyses, the results would indicate that a change in physical appearance does not seem to be accompanied by any great change in chemical composition.

The results of an analysis of the standard dust used in this experiment were as follows:

Moisture	1. 94
Volatile matter	35. 11
Fixed carbon	57. 73
Ash	5. 22
	100. 00

[Volatile matter : fixed carbon :: 37.82 : 62.18.]

A sample of coked dust from the outby exposures on the inby corner of the last cut-through and the air course was analyzed with results as follows:

Moisture	1. 51
Volatile matter	22. 32
Fixed carbon	42. 39
Ash	33. 78
	100. 00

[Volatile matter : fixed carbon :: 34.49 : 65.51.]

This analysis shows a decrease of the percentage of volatile matter in the ratio of volatile matter to fixed carbon, and a large increase in the percentage of ash, probably caused by partial combustion of the coal dust and to a mixing of the coal dust with some high-ash material from the roof or floor.

Analysis of a sample of the road dust showed the following results:

Moisture	2. 00
Volatile matter	24. 22
Fixed carbon	33. 01
Ash	40. 77
	100. 00

[Volatile matter : fixed carbon :: 42.32 : 57.68.]

This analysis shows a large increase in the percentage of ash, as might be expected, because the sample was taken from the entry bottom where the coal dust might have become mixed with incombustible material and because a large proportion of the combustible material in the coal dust had been consumed. In regard to the increased proportion of volatile matter to fixed carbon the possible explanation is that the sample contained a quantity of highly volatile soot which settled out of the smoke after the explosion, rather than that more fixed carbon than volatile matter had been burned in the explosion, but may be due to the water of combination of the included shale or limestone dust.

TEST 3.

Date.—January 31, 1912.

Purpose of test.—Study of the propagation of coal-dust explosions and the effect of a Taffanel stone-dust barrier.

Special conditions.—Subsequent to October 30, 1911, permanent shelving had been installed throughout the length of the main entry; 5 new circuit-breaker stations had been installed at points E 250, E 350, E 450, E 550, and E 650; and a reinforced-concrete stopping had been built in the first cut-through.

Point of origin of explosion.—Face of main entry, E 738.

Method of ignition.—Blow-out shot from a 1½-inch pipe in the coal.

Ignition charge.—Two pounds of FFF black blasting powder, tamped with 5 inches of damp clay stemming.

COAL DUST.

Source.—The coal dust was ground from bituminous coal from the Pittsburgh bed at Willock, Pa.

Size.—Over 95 per cent passed through a 100-mesh screen.

Analysis.—

Moisture	3.13
Volatile matter	32.71
Fixed carbon	54.40
Ash	9.76
	100.00
Sulphur	1.44

Zone.—Main entry, E 738 to E 654, or 84 feet.

Position.—E 738 [a] to E 722 on a bench placed just below the level of the hole containing the igniting charge; E 733 to E 654 on permanent side shelves on both sides of the entry.

Quantity.—One hundred and five pounds of coal dust: 26 pounds on bench and remainder on side shelves, distributed 1 pound per foot.

Inert zone.—The main entry was watered from E 650 to the opening. The air course was also sprinkled throughout its length.

[a] The main entry face was advanced from E 725 to E 738 in the interim between tests 2 and 3.

TAFFANEL BARRIER.

Location.—In the air course, extending from 5 to 85 feet outby third cut-through.

Number of shelves.—Eleven.

Distance between shelves.—About 8 feet from center to center.

Width of shelves.—Twenty-four inches.

Depth of shelves.—Two inches.

Depth of stone dust.—Seven and one-half to eight inches.

Area of obstruction.—13.81 per cent of total cross section.

Analysis of stone dust.—

Organic hydrogen	0.15
Organic carbon	1.98
Moisture (at 105° C.)	2.57
Inorganic volatile matter (combined water, CO_2, etc.)	8.42
Ash	86.88
	100.00

Ventilation and humidity readings.

Station.	Wet bulb.	Dry bulb.	Barometer.	Humidity.	Cross section.	Velocity.	Volume.
	° F.	*° F.*	*Inches.*	*Per cent.*	*Feet.*	*Feet per minute.*	*Cubic feet per minute.*
G 310[a]	26	29	28.89	67	6⅛ by 6⅓	192	7,488
E 650	43	45	28.85	86			
E 50	41	42	28.875	92	9 by 6½	75	4,388

[a] 310 feet from mouth of gallery.

INSTRUMENTS AND RECORDS.

MANOMETERS.

Location.—Manometer A (suction) at station E 50; manometer B (pressure) at station E 50; manometer C (pressure) at station E 150.

Springs.—Manometers B and C were equipped with 200-pound springs.

Records.—Pressure too small to be recorded.

PRESSURE CIRCUIT BREAKERS.

Location.—At stations E 50, E 150, E 250, E 350, E 450, E 550, E 650.

Adjustment.—Set to operate at a pressure of 5 pounds.

Records.—Pressure circuit breaker at station E 650 operated.

FLAME CIRCUIT BREAKERS.

Type.—Detonator, coated inside and outside with silver carbide (see p. 63).

Location.—Stations E 50 to E 650, inclusive.

Records.—Flame circuit breaker at station E 650 operated.

OUTSIDE MANIFESTATIONS.

A cloud of dust blew out the explosion-door section first. The doors at the top of the shaft blew open and a cloud of light-colored dust came out. At the main entry a little dust blew out the opening. The most noticeable feature outside the mine was the swirling up of the snow from the main opening to the end of the dump.

INSIDE OBSERVATIONS.

Few indications of violence were noted. The first door in the air course was blown open 2 feet. A board from the door was found in the air course 6 feet outby. The second door was cracked in the middle and the iron straps on it were bent inby. There was more or less coal dust scattered throughout the air course, there being heavy deposits of coal dust on the shelves of the Taffanel barrier.

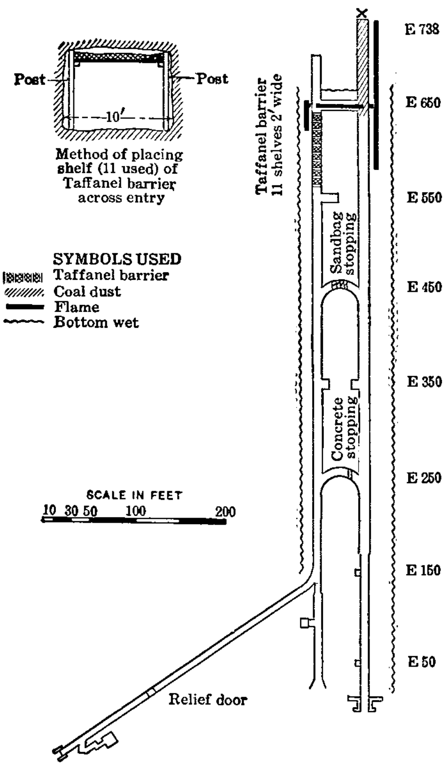


FIGURE 18.—Test 3, extent of flame and conditions of test.

Black damp.—The doors were closed so that the black damp could be cleared out. Three minutes after the doors had been closed a heavy cloud of smoke started to come out and continued for 15 minutes.

Length of flame.—The length of the flame was indicated by guncotton tufts that had been suspended from the roof at intervals of 25 feet. The flame in the entry was 159 feet long, and the branch flame in the third cut-through and in the air course was 63 feet long (fig. 18).

Efficiency of barrier.—It is to be noted that the flame did not extend through the barrier. The flame might or might not have extended farther if the barrier had not been there. The barrier probably did not have much of a quenching effect as the stone dust was only slightly disturbed.

TEST 4.

Date.—January 31, 1912.

Purpose.—To determine the possibility of an explosion from the same dust as was used in preceding test.

Point of origin of explosion.—Face of main entry, E 738.

Method of ignition.—Blown-out shot from 1½-inch pipe in the coal. The hole in which the igniting charge was placed was 2 feet 4 inches above the bottom, and 16 inches from the west rib. The axis of the hole intersected the floor 16 feet from the face.

Ignition charge.—Two pounds of FFF black blasting powder, tamped with 5 inches of damp clay stemming.

COAL DUST.

Zone.—E 738 to E 654, 84 feet.

Position.—E 738 to E 732 on bench placed just below the level of the hole containing the igniting charge; E 733 to E 654 on permanent side shelves on both sides of the entry.

Quantity.—Twenty-six pounds of fresh dust was placed on bench in front of shot; dust on the shelves was that remaining from the preceding test in which 105 pounds had been used.

Inert zone.—Preceding the previous test the main entry had been watered from E 650 to the opening. Some coal dust had been blown from the shelves onto the floor of the entry from E 650 outby, so that this zone was not as inert as it had been in test 3. The air course, for a like reason, had a thin coating of coal dust on the floor.

TAFFANEL BARRIER.

Location.—In the air course, extending from 5 to 85 feet outby the third cut-through.

Number of shelves.—Eleven.

Distance between shelves.—About 8 feet from center to center.

Width of shelves.—Twenty-four inches.

Depth of shelves.—Two inches.

Depth of stone dust.—Seven and one-half to 8 inches.

Obstruction.—13.81 per cent of the total cross section.

Analysis of stone dust.—

Organic hydrogen	0.15
Organic carbon	1.98
Moisture (at 105° C.)	2.57
Inorganic volatile matter (combined water, CO_2, etc.)	8.42
Ash	86.88
	100.00

INSTRUMENTS AND RECORDS.

No instruments were used in this test.

OUTSIDE MANIFESTATIONS.

The steel sheets over the explosion-door section rattled, but were not moved to any great extent by the explosion. The second puff blew open the east door on top of the air shaft. Eight well-defined puffs of smoke were seen to come from the shaft. The only indication of an explosion at the main entry was a flurry of snow and dust from the opening to the end of the dump.

INSIDE OBSERVATIONS.

An examination of the face of the entry showed that the pipe in which the charge had been placed was split its entire length, and the coal was broken for 18 inches back from the front of the hole.

Shelves from E 650 to E 350 had a fine coating of coal dust which had been blown from the dust zone. A deposit of coked dust was found on the east shelf outby the third cut-through.

The shelves from E 738 to E 610 were coated with soot deposited from the smoke of the explosion. A small deposit of coked dust was found on the shelves inby E 670.

LENGTH OF FLAME.

None of the strips of guncotton unaffected by the preceding explosion was affected by this explosion. It is probable that the length of flame of the two explosions was about the same.

TEST 5.

Date.—February 2, 1912.

Purpose.—In test 3 of January 31, the circuit breaker at station E 650 operated, but none of the other circuit breakers was acted on by sufficient pressure to break the circuits. It was thought that had the circuit breakers in the preceding explosion been so adjusted that they would have been operated by less pressure, more records would have been obtained. Therefore, this test was made to determine what was the least pressure to which they could be adjusted and still not be operated by a blown-out shot in the coal face.

Point of origin of explosion.—Face of main entry, E 744.

Method of ignition.—Blown-out shot from 1½-inch pipe in the coal.

Charge.—Two pounds of FFF black blasting powder tamped with 5 inches of damp shale dust.

Coal dust.—No coal dust used in this test.

Inert zone.—Main entry watered the entire distance.

Ventilation.—In order to determine whether the mine was producing any gas, the fan was shut down for 14 hours preceding this test and two samples of gas were taken; one at the face of the air course and one at the face of the entry, with results as follows:

Analysis of air-course sample.

CO_2	0.07
O_2	20.59
CO	.00
CH_4	.06
N	79.28
	100.00

Analysis of entry sample.

CO_2	0.06
O_2	20.58
CO	.00
CH_4	.04
N	79.32
	100.00

The above results of analyses show that very little methane had accumulated during the time the fan had been shut down. On the basis of the analysis results no perceptible amount of gas would be found with the ventilation in normal condition. After the samples had been taken the fan was started so that the ventilation conditions of this test would be similar to those of test 3.

INSTRUMENTS AND RESULTS.

Pressure circuit breakers.—Two pressure circuit breakers were installed in the station at E 650; one was adjusted so as to be operated by a pressure of 1 pound and the other by a pressure of 2 pounds.

Length of flame.—Guncotton tufts at E 704 and E 729 were ignited either by the flame from the shot or more probably by a flying particle of burning powder.

Results.—Only the circuit breaker set at 1 pound operated. It was concluded, therefore, that circuit breakers set at 2 pounds would not be operated by the pressure from a blow-out shot from a 1½-inch pipe, with the charge and the stemming of this test.

TEST 6.

Date.—February 3, 1912.

Purpose.—Study of the propagation of a coal-dust explosion, and of the effect of Taffanel stone-dust barrier with coal-dust zone of 190 feet.

Origin of explosion.—Face of the main entry, E 744.

Method of ignition.—Blown-out shot from 1½-inch pipe in the coal.

Charge.—Two pounds of FFF black blasting powder, tamped with 5 inches of damp shale dust.

COAL DUST.

Source.—The coal dust was ground from bituminous coal from the Pittsburgh bed at Willock, Pa.

Size.—Over 95 per cent passed through a 100-mesh screen.

Analysis.—

Moisture	3.13
Volatile matter	32.71
Fixed carbon	54.40
Ash	9.76
	100.00
Sulphur	1.44

Zone.—E 744 to E 554, or 190 feet.

Position.—E 744 to E 728, on bench placed just below the level of the hole containing the ignition charge; E 733 to E 554, on permanent side shelves on both sides of the entry.

Quantity.—Twenty-five pounds of coal dust on the bench; 175 pounds on the side shelves; loading equivalent to 1.05 pounds per linear foot of entry.

Inert zone.—Main entry, from E 554 outby, was sprinkled. Air course also was sprinkled before the explosion.

TAFFANEL BARRIER.

Location.—In the air course, extending from 5 to 85 feet outby third cut-through.

Number of shelves.—Eleven.

Distance between shelves.—About 8 feet from center to center.

Width of shelves.—Twenty-four inches.

Depth of shelves.—Two inches.

Depth of stone dust.—Seven and one-half to eight inches.

Obstruction.—13.81 per cent of total cross section.

Analysis of stone dust.—The coal dust that had settled on the surface of the stone dust after explosion tests 3 and 4 was scraped off, and ground shale dust was heaped on the shelves until they would hold no more. A sample of the dust was taken from various parts of a carload of shale. Its analysis follows:

Organic hydrogen	0.39
Organic carbon	7.59
Moisture (at 105° C.)	3.94
Inorganic volatile matter (combined water, CO_2, etc.)	5.42
Ash	82.66
	100.00

VENTILATION.

Air and humidity readings taken at two points just prior to the explosion were as follows:

Air and humidity readings, test 6.

Station.	Wet bulb.	Dry bulb.	Barometer.	Humidity.	Cross section.	Velocity.	Volume.
	°F.	*°F.*	*Inches.*	*Per cent.*	*Feet.*	*Feet per minute.*	*Cubic feet per minute.*
E 180	45	46½	28.96	89	6½ by 9	80	4,680
Third cut-through	39	40	28.96	92	6⅙ by 9	60	3,330

Analysis of mine air.—A sample of mine air (No. 2078) was taken at the face of the main entry just before firing the shot in order to determine whether any methane was present. The results of analysis were as follows:

CO_2	0.06
O	19.86
CO	.00
CH_4	.02
N	80.06
	100.00

The analysis shows 0.02 per cent of methane, and as the possible error would not exceed 0.01 per cent, one may be assured that there was only a slight trace of gas present, too little to affect the result of the shot. It is also probable that even a trace could not be found near the cut-through.

INSTRUMENTS AND RECORDS.

MANOMETERS.

Location.—Manometer A (suction) at station E 50; manometer B (pressure) at station E 50; manometer C (pressure) at station E 150.

Springs.—Manometers B and C were equipped with 200-pound springs.

PRESSURE CIRCUIT BREAKERS.

Location.—Stations E 50, E 150, E 250, E 350, E 450, E 550, E 650.

Adjustment.—Set to operate at a pressure of 2 pounds.

FLAME CIRCUIT BREAKERS.

Location.—Stations E 50, E 150, E 250, E 350, E 450, E 550, E 650.

RECORDS.

Manometers.—Pressure too small to be recorded (less than 1 pound per square inch).

Pressure circuit breakers.—Operated at station E 650.

Flame circuit breakers.—Operated at stations E 650 and E 550.

Velocity of flame propagation.—The flame reached station E 650, 1.8714 seconds after ignition and station E 550, 2.6617 seconds after ignition; the time between those stations was 0.7903 second, and the velocity 127 feet per second.

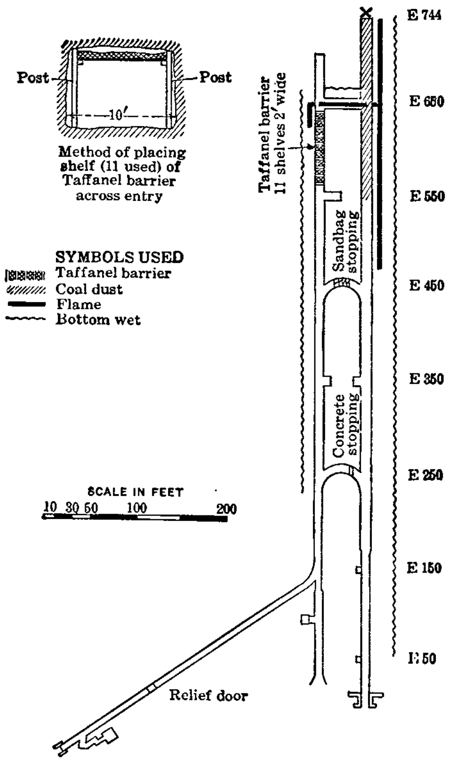


FIGURE 19.—Test 6, extent of flame and conditions of test.

OUTSIDE MANIFESTATIONS.

Violence.—The steel sheets of the explosion-door section were rattled by the explosion, and some of them were moved slightly toward the steel gallery. The only other outside evidence of an explosion was the swirl of snow and dust from the opening to the end of the dump.

INSIDE OBSERVATIONS.

The curtain hanging across the air course inby the shaft was carried inby 26 yards. The board door outby the shaft was broken outward.

Length of flame.—The length of flame in the main entry was indicated by the guncotton tufts suspended along the entry to be 265 feet long (fig. 19). The branch flame in the cut-through and air course was 72 feet long.

EFFICIENCY OF BARRIER.

The flame extended farther into the barrier than it did in test 3, in which the length of the coal-dust loading in the main entry was 100 feet less than in this experiment. The stone dust was not disturbed very much by the explosion, so that its effect in quenching the flame was probably not great. A sample of the coal dust left on the shelves after the explosion was taken, the analysis of which gave the following results:

Moisture	2.85
Volatile matter	33.02
Fixed carbon	54.31
Ash	9.82
	100.00
Sulphur	1.24

A comparison of the ratio of volatile matter to fixed carbon (37.81: 62.19) with the ratio of volatile matter to fixed carbon in the original coal dust (37.55:62.45) shows that the percentage of volatile matter was not materially changed.

Of the 200 pounds of coal dust used in this test, 76 pounds remained on the shelves after the explosion.

TEST 7.

Date.—February 5, 1912.

Purpose.—Study of the propagation of a coal-dust explosion and the effect of Taffanel barrier with a coal-dust zone of 290 feet.

Point of origin of explosion.—Face of main entry, E 744.

Method of ignition.—Blown-out shot from 1½-inch pipe in the coal.

Charge.—Two pounds of FFF black blasting powder, tamped with 5 inches of damp clay.

COAL DUST.

Source.—The coal dust was ground from bituminous coal from the Pittsburgh bed at Willock, Pa.

Size.—Over 95 per cent passed through a 100-mesh screen.

Analysis.—

Moisture	3.13
Volatile matter	32.71
Fixed carbon	54.40
Ash	9.76
	100.00
Sulphur	1.44

Zone.—From E 744 to E 454, or 290 feet.

Position.—From E 744 to E 728 on a bench placed just below the level of the hole containing the igniting charge; from E 733 to E 454 on permanent shelves along both sides of the entry.

Quantity.—Twenty-six pounds of coal dust was placed on the bench and 324 pounds was along the side shelves. This is equivalent to an average loading of 1.21 pounds per linear foot.

Inert zone.—The main entry was watered from E 450 to the opening; the air course was also sprinkled to render it inert.

TAFFANEL BARRIERS.

Location.—In the air course, extending from 5 to 85 feet outby cut-through.

Number of shelves.—Eleven.

Distance between shelves.—About 8 feet from center to center.

Width of shelves.—Twenty-four inches.

Depth of shelves.—Two inches.

Depth of stone dust.—Seven and one-half to eight inches.

Obstructions.—13.81 per cent of total cross section.

Analysis of stone dust.—

Organic hydrogen	0. 39
Organic carbon	7. 59
Moisture (at 105° C.)	3. 94
Inorganic volatile matter (combined water, CO_2, etc.)	5. 42
Ash	82. 66
	100. 00

Humidity readings.

Station.	Wet bulb.	Dry bulb.	Humidity.
	° F.	*° F.*	*Per cent.*
Outside	12	14	63
E 250	45	45	100
E 450	45	46	93

INSTRUMENTS AND RECORDS.

MANOMETERS.

Location.—Manometer A (suction) at station E 50; manometer B (pressure) at station E 50; manometer C (pressure) at station E 150.

Springs.—Manometers B and C were equipped with 200-pound springs.

PRESSURE CIRCUIT BREAKERS.

Location.—Stations E 50, E 150, E 250, E 350, E 450, E 550, E 650.

Adjustment.—Set to operate at a pressure of 2 pounds.

FLAME CIRCUIT BREAKERS.

Type.—Detonator with silver-carbide stick (p. 63).

Location.—Stations E 50, E 150, E 250, E 350, E 450, E 550, E 650.

RECORDS.

Manometers.—Pressures were too small to be recorded.

Velocity.—No pressure circuit breakers operated. Flame circuit breakers at stations E 650 and E 550 operated. The flame reached station E 650, 1.4917 seconds after ignition and station E 550, 2.1149 seconds after ignition. The time between stations was 0.6232 second, and the velocity 160 feet per second.

MANIFESTATIONS.

Outside.—The only evidence of an explosion outside was the rattling of the steel sheets of the explosion-door section, and the appearance of a slight cloud of dust at the mouth of the main opening.

Inside.—The door in the air course had been previously removed and the curtains replacing it were not torn down by the explosion. There were no signs of violence in any part of the mine.

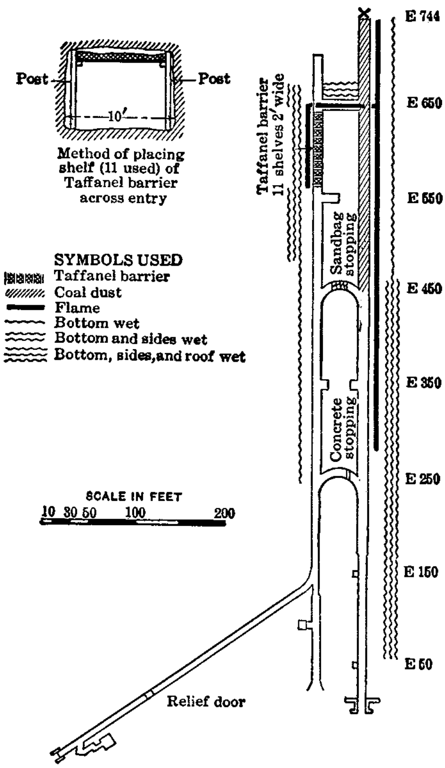


FIGURE 20.—Test 7, extent of flame and conditions of test.

LENGTH OF FLAME.

The flame in the main entry extended from the face to E 279, or 465 feet (fig. 20). In the cut-through air-course branch the flame extended 135 feet or to the outby end of the Taffanel barrier. The stone dust on the barrier was disturbed only slightly and it is uncertain just how much of a quenching effect the barrier may have had on the flame.

ANALYSES MADE AFTER THE EXPLOSION.

COAL DUST.

A coal-dust sample (No. 13297) was taken from the dust remaining on the shelves after this explosion and was analyzed, the results being as follows:

Moisture	3.01
Volatile matter	32.64
Fixed carbon	50.57
Ash	13.78
	100.00
Sulphur	1.18

Comparison of the ratio of volatile matter to fixed carbon (39.23: 60.77) with the ratio of volatile matter to fixed carbon in the original dust (37.55: 62.45) indicates again an increase in volatile matter and a corresponding decrease in the fixed carbon. It is probable that this change was again due to a mixing of the original dust with some soot from the explosion.

One hundred and thirty pounds out of the 350 pounds put on the shelves for this test remained after the explosion.

ROAD DUST.

A road-dust sample (No. 13295) from the air course between the second and third cut-throughs was taken after the explosion, and was analyzed, with the following results:

Moisture	16.02
Volatile matter	17.10
Fixed carbon	13.91
Ash	52.97
	100.00
Sulphur	.84

The high content of ash and moisture would render this road dust nonexplosive, and might possibly even have a quenching effect on the flame of the explosion.

MINE AIR.

A sample of mine air (No. 2079) was taken at the face of the main entry as soon after the explosion as it was possible to reach this point without a helmet. The analysis showed the following results:

CO_2	0.04
O_2	20.93
CO	.00
CH_4	Trace.
N	79.03
	100.00

This sample showed a surprisingly small percentage of black damp and no carbon monoxide; the smell and the presence of smoke indicated worse conditions than were shown by this sample.

A sample of mine air (No. 2081) was also taken inby station E 650 about the same time as the preceding sample, its analysis showing the following results:

CO_2	0.08
O_2	20.91
CO	.00
CH_4	Trace.
N	79.01
	100.00

This analysis is almost a duplicate of that of the preceding sample.

TEST 8.

Date.—February 7, 1912.

Purpose of test.—Study of propagation of a coal-dust explosion and the effect of Taffanel barrier with a coal-dust zone of 290 feet.

Point of origin of explosion.—Face of main entry, E 744.

Method of ignition.—Blown-out shot from a cannon placed near the face.

Charge.—Two and three-fourths pounds of FFF black blasting powder tamped with 3 inches of damp shale dust.

COAL DUST.

The coal dust was ground from bituminous coal from the Pittsburgh bed at Willock, Pa.

Size.—Over 95 per cent passed through a 100-mesh screen.

Analysis.—

Moisture	2.94
Volatile matter	33.98
Fixed carbon	54.36
Ash	8.72
	100.00
Sulphur	1.32

The sample analyzed was taken from the dust on the shelves just preceding the explosion.

Zone.—From the face at E 744 to E 454, or 290 feet.

Position.—E 742 to E 726 on a bench placed just below the level of the bore hole of the cannon; E 733 to E 454 on permanent side shelves along both sides of the entry.

Quantity.—Thirty pounds of coal dust on the bench and 270 pounds scattered along the shelves. This is equivalent to an average loading of 1.03 pounds per linear foot.

Inert zone.—The main entry from E 450 outby to the opening, the last cut-through, and the air course were watered to render them inert.

TAFFANEL BARRIER.

Location.—In the air course, extending from 5 to 85 feet outby third cut-through.

Number of shelves.—Eleven.

Distance between shelves.—About 8 feet from center to center.

Width of shelves.—Twenty-four inches.

Depth of shelves.—Two inches.

Depth of stone dust.—Seven and one-half to eight inches.

Obstructions.—13.81 per cent of total cross section.

Shale dust.—A sample of the ground shale and limestone on the Taffanel-barrier shelves before the explosion was analyzed, with the following results:

Organic hydrogen	0.41
Organic carbon	7.48
Moisture (at 105° C.)	4.28
Inorganic volatile matter (combined water, CO_2, etc.)	7.25
Ash	80.58
	100.00

VENTILATION AND HUMIDITY READINGS.

Ventilation.—The fan stopped two minutes before the explosion, so that the explosion probably occurred in still air.

Humidity.—

Station.	Wet bulb.	Dry bulb.	Humidity.
	°*F.*	°*F.*	*Per cent.*
Third cut-through	36½	38½	83
E 450	40½	42½	85
Outside	18	20	70

INSTRUMENTS AND RECORDS.

MANOMETERS.

Location.—Manometer A (suction) at station E 50; manometer B (pressure) at station E 50; manometer C (pressure) at station E 150.

Springs.—Manometers B and C were equipped with 200-pound springs.

PRESSURE CIRCUIT BREAKERS.

Location.—At stations E 50, E 150, E 250, E 350, E 450, E 550, E 650.

Adjustment.—Set to operate at a pressure of 2 pounds.

FLAME CIRCUIT BREAKERS.

Type.—Detonator type with silver-carbide stick.

Location.—At stations E 50, E 150, E 250, E 350, E 450, E 550, E 650.

RECORDS.

Manometers.—The pressure was too low to operate manometers B and C. The record obtained on suction manometer A is reproduced in figure 21.

Velocity.—Pressure circuit breakers at stations E 650, E 550, and E 450 operated.

Flame circuit breakers from station E 650 to station E 250, inclusive, operated.

Velocity of propagation of explosion, test 8.

Station.	Pressure wave.			Flame.		
	Total time from ignition.	Time between stations.	Velocity between stations.	Total time from ignition.	Time between stations.	Velocity between stations.
	Seconds.	*Seconds.*	*Feet per second.*	*Seconds.*	*Seconds.*	*Feet per second.*
E 650	0.0685			0.6216		
E 550	.1565	0.0880	1,136	1.0771	0.4555	220
E 450	.2461	.0896	1,116	1.4715	.3944	254
E 350	....	....	....	1.7226	.2511	398
E 250	....	....	....	3.6857	1.9631	51

MANIFESTATIONS.

Outside.—The only outside evidence of an explosion was a rattling of steel sheets over the explosion-door section, and a cloud of dust and smoke and flurries of snow swirling from the main opening to the end of the dump. The brace on the west side of the car dump,

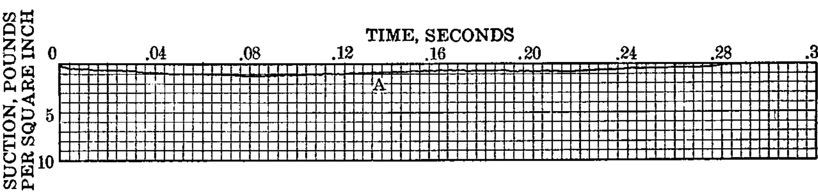


FIGURE 21.—Manometric curve, test 8, pressure below atmospheric.

which was standing at the edge of the slate dump, was broken by a flying board from a concrete form that had been resting against the concrete wall at the opening. Other pieces of the same concrete form were sucked into the entry to station E 50. The top bar of the entry gates was broken into two pieces; one piece was found on the dump 120 feet from the opening, and the other on the east side of the slate dump. One part of the board "Danger" sign on the air course was blown 54 feet and the other 72 feet in from the opening. The last four sheets on the explosion-door section were lifted completely out of place, and fell on the movable section of the steel gallery.

Inside.—There was considerable coke on the inby and outby exposures of the shelves at E 240, E 340, and E 440; the rib was soot covered from E 300 to the face; at E 304 the coal was blistered, and many other small blisters were noted between this point and the face. The roof was badly blistered at E 440. A deposit of coked dust was found on the shelves at E 479. There was some coked dust on the outby end of the shelf at E 550. At E 590 there were large quantities of coked dust on the outby exposures of the posts and bolt ends; at E 640 there was coked dust on the outby side of the posts and bolt ends; at E 654 there was coked dust on the outby corner and coke bubbles on the inby corner of the third cut-through.

LENGTH OF FLAME.

The length of flame, as indicated by guncotton tufts suspended along the entry, was 552 feet from the face to E 192 (fig. 22). The branch flame on the air course extended for 225 feet outby the third cut-through. About 4 to 5 inches of stone dust remained on the shelves of the barrier after the explosion. The flame did not seem to be much checked by the barrier.

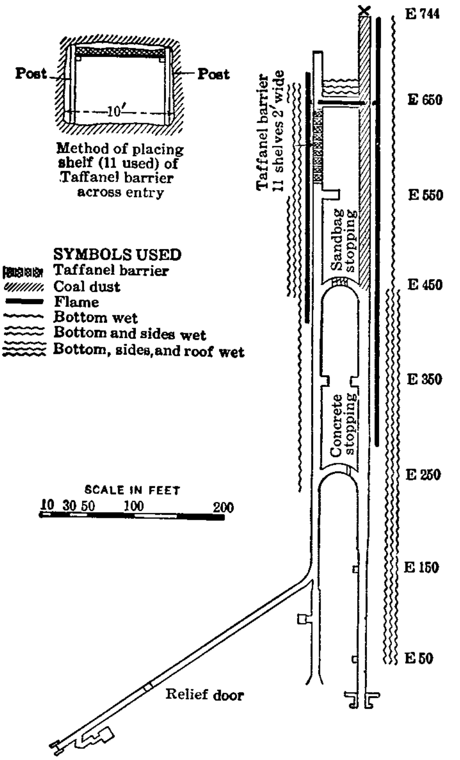


FIGURE 22.—Test 8, extent of flame and conditions of test.

SAMPLES ANALYZED.

A sample of the coal dust remaining on the shelves after the explosion was taken and analyzed, with results as follows:

Moisture	2.88
Volatile matter	32.43
Fixed carbon	51.88
Ash	12.81
	100.00
Sulphur	1.27

A comparison of the ratio of fixed carbon to volatile matter (38.47 : 61.53) with the ratio of fixed carbon to volatile matter of the original sample (38.47 : 61.53) shows that the dust remaining on the shelves after the explosion was practically unaffected by the explosion. The increase in ash in the sample after the explosion was probably due to a mixing of ash from the consumed dust or road-dust material with the dust remaining on the shelves. Out of the 300 pounds put on the shelves for this test 87 pounds still remained after the explosion. As the quantity remaining on the shelves after this explosion was smaller than that remaining after the preceding explosion, it would seem that the higher pressures developed caused more of the dust to be thrown in suspension.

A sample of dust that had settled out on the surface of a side support on which the shelves of the Taffanel barrier rest was taken and analyzed with results as follows:

Moisture	3.21
Volatile matter	12.24
Fixed carbon	11.20
Ash	73.35
	100.00
Sulphur	.64

The material of this sample had been in suspension immediately following the explosion, and the analysis indicates that the material was a mixture, probably of stone dust, coal dust, and soot.

TEST 9.

Date.—February 8, 1912.

Purpose.—In tests 6 and 8, pressure circuit breakers set to release at a pressure of 2 pounds were operated, seemingly by the pressure wave produced by the blown-out shot from the cannon. This test was made under the same conditions as those of the preceding test except that no coal-dust loading was used, so as to ascertain whether the same circuit breakers would be operated.

Point of origin of explosion.—Face of main entry, E 744.

Method of ignition.—Blown-out shot from bore hole of cannon.

Ignition charge.—Two and three-fourths pounds of FFF black blasting powder tamped with 4 inches of damp clay.

Coal dust.—No coal dust used in this test.

Length of flame.—The guncotton tufts at E 729 and E 704 were ignited by flame or flying pieces of burning powder.

INSTRUMENTS AND RECORDS.

INSTRUMENTS.

Location.—Pressure circuit breakers were located at stations E 50, E 150, E 250, E 350, E 450, E 550, and E 650.

Adjustment.—All the circuit breakers were adjusted to operate at a pressure of 2 pounds.

RECORDS.

The circuit breakers at E 450, E 550, and E 650 operated, the records being as follows:

Velocity of pressure wave, test 9.

Station.	Total time from ignition.	Time between stations.	Velocity between stations.
	Seconds.	*Seconds.*	*Feet per second.*
E 650	0.0683		
		0.0900	1,111
E 550	.1583		
		.0910	1,099
E 450	.2493		

It was now necessary to make further tests to ascertain the minimum pressure to which the circuit breakers could be adjusted and still not be operated by the pressure from a blown-out shot similar to the one fired in this test.

TEST 10.

Date.—February 9, 1912.

Purpose.—Determination of minimum pressure to which pressure circuit breakers could be adjusted and still not be operated by a blown-out shot from a cannon with the usual charge and stemming.

Point of origin of explosion.—Face of main entry, E 744.

Method of ignition.—Blown-out shot from cannon.

Ignition charge.—Two and three-fourths pounds of FFF black powder tamped with 4 inches of damp clay.

Coal dust.—No coal dust used in this test.

Inert zone.—The entry was sprinkled throughout its entire length in order that the road dust might be rendered inert.

Instruments.—Two pressure circuit breakers were installed at station E 650. No. 6 was adjusted to operate at a pressure of 3 pounds and No. 10 at a pressure of 4 pounds.

Results.—Both circuit breakers operated.

Length of flame.—Guncotton tufts at point E 704 were burned by flame or flying pieces of burning powder.

TEST 11.

Date.—February 9, 1912.

Purpose.—Determination of minimum pressure to which circuit breakers could be adjusted and still not be operated by a blown-out shot from a cannon with the usual charge and stemming.

Point of origin of explosion.—Face of main entry, E 744.

Method of ignition.—Blown-out shot from cannon.

Ignition charge.—Two and three-fourths pounds of FFF black blasting powder tamped with 4 inches of damp clay.

Coal dust.—None used.

Inert zone.—The entry was sprinkled for its entire length.

Instruments.—Two circuit breakers were installed at station E 650, one adjusted to operate at a pressure of 5 pounds and the other at a pressure of 6 pounds.

Results.—Neither of the pressure circuit breakers operated.

Conclusions.—In tests 9, 10, and 11 circuit breakers set to release at pressures of 4 pounds or less were operated by the pressure from the blown-out shot, whereas those set to operate at a pressure of 5 and 6 pounds did not operate. As a result of these tests it was decided in future tests in which the igniting shot was from the cannon with the usual charge and stemming to set the pressure circuit breakers to operate at a pressure of 5 pounds.

TEST 12.

Date.—February 10, 1912.

Purpose.—Study of the propagation of coal-dust explosions and the efficiency of Taffanel barriers.

Point of origin of explosion.—Face of main entry, E 744.

Method of ignition.—Blown-out shot from cannon.

Ignition charge.—Two and three-fourths pounds of FFF black blasting powder, tamped with 4 inches of damp shale dust.

COAL DUST.

Source.—The coal dust was ground from bituminous coal from the Pittsburgh bed at Willock, Pa.

Size.—95 per cent passed through a 100-mesh screen.

Analysis.—

Moisture	2.13
Volatile matter	35.29
Fixed carbon	55.69
Ash	6.89
	100.00
Sulphur	1.20

Zone.—From E 744 to E 34, or 710 feet.

Position.—E 742 to E 726 on a bench placed just below the level of the bore hole of the cannon; E 733 to E 34 on permanent side shelves on both sides of the entry.

Quantity.—Four hundred and eighty-two pounds. The first 290 feet was loaded at the rate of 1 pound per linear foot; the outer 420 feet was loaded at the rate of 0.457 pound per foot.

Inert zone.—The third cut-through and the air course were sprinkled; the floor of the main entry was also sprinkled to render the road dust inert.

TAFFANEL BARRIER.

Location.—In the air course, from 5 to 85 feet outby the third cut-through.

Number of shelves.—Thirteen.

Distance between shelves.—Six feet center to center.

Width of shelves.—Twenty inches.

Depth of shelves.—One inch.

Depth of stone dust.—Six and one-half inches.

Area of obstruction.—12.1 per cent.

Analysis of stone dust.—

Organic hydrogen	0.39
Organic carbon	7.59
Moisture (at 105° C.)	3.94
Inorganic volatile matter (combined water, CO_2, etc.)	5.42
Ash	82.66
	100.00

VENTILATION AND HUMIDITY.

At the time of the explosion about 5,000 cubic feet of air was moving through the last cut-through. A sample (No. 2252) of mine air, taken at the face of the main entry just prior to firing the shot, did not show any methane.

At the third cut-through the dry-bulb thermometer registered 35° F., and the wet-bulb thermometer 34° F., the humidity being 91 per cent

INSTRUMENTS AND RECORDS.

MANOMETERS.

Location.—Manometer A (suction) at station E 50; manometer B (pressure) at station E 50; manometer C (pressure) at station E 150.

Springs.—Manometers B and C were equipped with 200-pound springs.

PRESSURE CIRCUIT BREAKERS.

Location.—At stations E 50, E 150, E 250, E 350, E 450, E 550, and E 650.

Adjustment.—Set to operate at a pressure of 5 pounds.

FLAME CIRCUIT BREAKERS.

Type.—Detonator type with silver-carbide stick.

Location.—At stations E 50, E 150, E 250, E 350, E 450, E 550, and E 650.

RECORDS.

Pressure.—Too low to be recorded by manometers B and C. The record obtained on the suction manometer is reproduced in figure 23.

Velocity.—Pressure circuit breaker at station E 650 operated; flame circuit breakers at stations E 650, E 550, E 450, and E 350 operated. Tabulated results were as follows:

Velocity of flame, test 12.

Station.	Total time from ignition.	Time between stations.	Velocity between stations.
	Seconds.	*Seconds.*	*Feet per second.*
E 650	0.5972		
		0.6540	153
E 550	1.2512		
		.6210	161
E 450	1.8722		
		.4448	225
E 350	2.3170		

OUTSIDE MANIFESTATIONS.

The steel sheets of the explosion-door section were thrown out of place. No flame was noted at the main opening, but a cloud of smoke shot out 100 to 150 feet.

INSIDE OBSERVATIONS.

Little violence was noted. No shelves were thrown down. Only three bags of the stopping in the second cut-through were displaced. It was estimated that 4 to 5 inches of the stone dust remained on the shelves of the barrier.

LENGTH OF FLAME.

The flame extended from E 744 to E 279, or 465 feet (fig. 24). The length in the air course was 85 feet. It was noted that the flame did not extend beyond the Taffanel barrier.

AFTERDAMP.

The mine was filled with smoke and afterdamp; clearing it for the next explosion took 45 minutes.

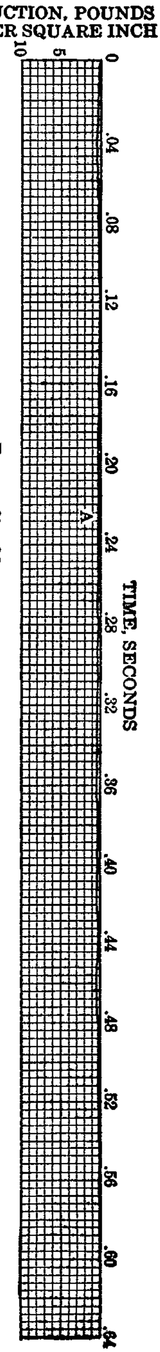


FIGURE 23.—Manometric curve, test 12, pressure below atmospheric.

TEST 13.

Date.—February 10, 1912.

Purpose.—To ascertain whether an explosion could be produced from dust that had been exposed to the previous explosion.

Point of origin of explosion.—Face of main entry, E 744.

Method of ignition.—Blown-out shot from 1½-inch pipe in coal.

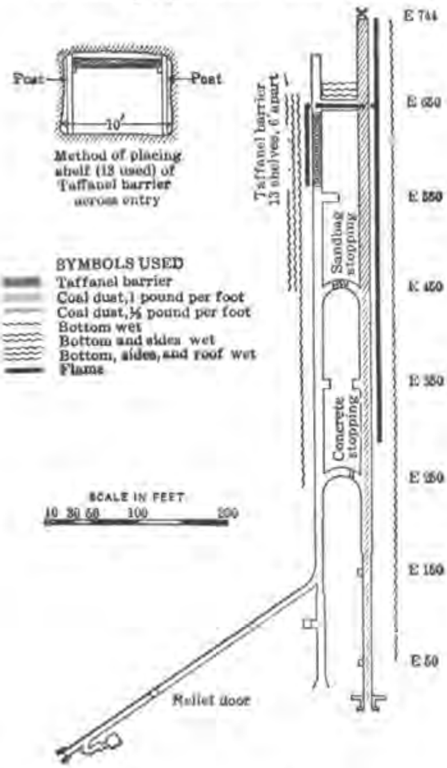


FIGURE 24.—Test 12, extent of flame and conditions of test.

Charge.—Two pounds of FFF black blasting powder, tamped with 4 inches of damp shale dust.

COAL DUST.

Source.—The dust was ground from bituminous coal from the Pittsburgh bed at Willock, Pa.

Size.—Ninety-five per cent passed through a 100-mesh screen.

Zone.—From E 744 to the main opening, 744 feet.

Position.—E 742 to E 726 on bench placed just below the level of the hole containing the igniting charge; E 733 to the main opening on side shelves or on the floor.

Quantity.—Twenty-five pounds of fresh coal dust was placed on the bench at the face. Throughout the remainder of the coal-dust zone the coal dust remaining after the preceding test was left as the load for this experiment.

TAFFANEL BARRIER.

Location.—In the air course, extending from 5 to 85 feet outby the third cut-through.

Number of shelves.—Thirteen.

Distance between shelves.—Six feet from center to center.

Width of shelves.—Twenty inches.

Depth of shelves.—One inch.

Depth of stone dust.—Four to five inches.

Analysis of stone dust.—

Organic hydrogen	0.39
Organic carbon	7.59
Moisture (at 105° C.)	3.94
Inorganic volatile matter (combined water, CO_2, etc.)	5.42
Ash	82.66
	100.00

OUTSIDE MANIFESTATIONS.

The steel sheets of the explosion-door section were disarranged. The smoke and coal dust shot out of the main opening for a distance or 100 to 150 feet.

INSIDE OBSERVATIONS.

Little violence was manifest. The curtain in the air course was blown down; a few of the bags in the cut-through were disarranged. The shelves of the Taffanel barrier were not disturbed.

LENGTH OF FLAME.

None of the guncotton tufts not affected by the preceding test was affected by this test, so that the length of the flame was manifestly not greater than in the preceding explosion. No recording instruments were used in this test.

TEST 14.

Date.—February 19, 1912.

Purpose.—To study the propagation of coal-dust explosions, and the efficiency of Taffanel barriers.

Point of origin of explosion.—Face of main entry, at E 744.

Method of ignition.—Blown-out shot from cannon.

Ignition charge.—Two and three-fourths pounds of FFF black blasting powder, tamped with 4 inches of damp shale dust.

COAL DUST.

Source.—The coal dust was ground from bituminous coal from the Pittsburgh bed at Willock, Pa.

Size.—Over 95 per cent passed through a 100-mesh screen.

Analysis.—

Moisture	3.30
Volatile matter	34.37
Fixed carbon	55.06
Ash	7.27
	100.00
Sulphur	1.25

Zone.—E 744 to E 34, or 710 feet.

Position.—E 742 to E 726 on bench placed just below the level of the bore hole of the cannon; E 733 to E 34 on permanent side shelves on both sides of the entry.

Quantity.—Six hundred and sixty pounds; loaded 0.93 pound per foot; equivalent to 0.248 ounce per cubic foot, or 248 grams per cubic meter.

Inert zone.—No watering was done for this test, but as there was a very large proportion of shale dust and clay in the road dust on the air course this was probably an inert zone.

TAFFANEL BARRIER.

Location.—In the air course, extending from 5 to 85 feet outby the third cut-through.

Number of shelves.—Thirteen.

Distance between shelves.—Six feet from center to center.

Width of shelves.—Twenty inches.

Depth of shelves.—One inch.

Depth of stone dust.—Six and one-half inches.

Analysis of stone dust—

Organic hydrogen	0.39
Organic carbon	7.59
Moisture (at 105° C.)	3.94
Inorganic volatile matter (combined water, CO_2, etc.)	5.42
Ash	82.66
	100.00

VENTILATION AND HUMIDITY.

At station E 550, where the cross section was 6½ by 9 feet, the velocity of the air was 104 feet per minute, the quantity being 6,084 cubic feet per minute. The humidity readings were as follows:

Humidity readings, test 14.

Station.	Wet bulb.	Dry bulb.	Humidity.
	°F.	*°F.*	*Per cent.*
Outside	45	49	74
E 250	43	45	86
E 550	47	48	93

INSTRUMENTS AND RECORDS.

MANOMETERS.

Location.—Manometer A (suction) at station E 50; manometer B (pressure) at station E 50; manometer C (pressure) at station E 150.

Springs.—Manometers B and C were equipped with 200-pound springs.

PRESSURE CIRCUIT BREAKERS.

Location.—At stations E 50, E 150, E 250, E 350, E 450, E 550, and E 650.

Adjustment.—Set to operate at a pressure of 5 pounds.

FLAME CIRCUIT BREAKERS.

Type.—Detonator type with silver-carbide stick.

Location.—At stations E 50, E 150, E 250, E 350, E 450, E 550, and E 650.

TIN-FOIL STRIPS.

In order to determine their suitability for use in flame circuit breakers, in this test four strips of tin foil of different thicknesses were placed on the shelves opposite stations E 50 to E 650, inclusive.

RECORDS.

Pressures.—The motors running the drums of the manometers failed to run; therefore only the maximum pressures were recorded. The records showed a pressure of 14.7 pounds at station E 150 and of 5.6 pounds at station E 50.

Velocity records.—The pressure circuit breakers at stations E 650, E 350, E 150, and E 50 operated; flame circuit breakers at stations E 650, E 450, E 350, and E 250 operated. The failure of the pressure and flame circuit breakers at station E 550 to operate prevented the obtaining of records of the circuit breakers at the stations outby this point. All tin-foil strips, except the two thickest at station E 50, were fused by the flame.

OUTSIDE MANIFESTATIONS.

A great cloud of dust swept out the main opening $1\frac{2}{5}$ seconds after the igniting shot had been fired. When the cloud had seemingly extended 50 to 75 feet from the opening, the flame shot through it, accompanied by a sharp crack, due probably to detonation of coal dust. The wave coming out of the gallery entry raised the steel sheets of the explosion-door section and piled them one upon another at the end of that section. The car dump standing at the top of the slate pile was blown over and landed down at the dam, one footboard having been broken. A barrel containing some ice was blown from a point 75 feet in front of the main entry to the fence near the slate dump. The "Danger" signboard on the air course was blown 100 feet distant. A piece of brattice cloth from the air-course curtain 75 feet inby the opening was blown outby to the air-course entrance.

INSIDE OBSERVATIONS.

A curtain packed in the crevices above the door frame inby the shaft was sucked inby 15 feet from its original position. An electric-light wire extending from the end of the concrete section in the air course to the first crosscut was blown outby so that it stretched from the end of the concrete to the intersection of the gallery and the air course.

Most of the dust on the Taffanel shelves was blown off. The first shelf outby the cut-through was blown down, and the second was swung around until it was parallel with the side of the entry.

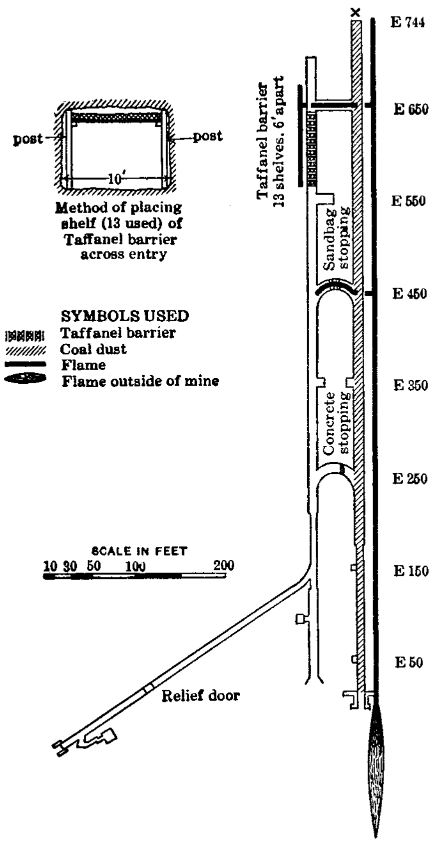


FIGURE 25.—Test 14, extent of flame and conditions of test.

In the main entry the mine track at E 530 seemed to have been raised slightly, as the ballast was very loose. This was possibly caused by the suction following the explosion wave.

The bags of the top 2 feet of the sandbag stopping in the second cut-through were blown out. Some bags were thrown toward the entry, but many more were thrown toward the air course. Many of these bags were upset and the sand spilled.

At E 390 the east end of one of the ties was bent forward 45°. This tie was broken where the rail was spiked to it. The rail had probably been slightly fractured at this point preceding the explosion. The post holding the shelves at E 294 was pushed into the groove in the rib 1½ inches. The floor from E 220 to E 160 was raised several inches, the ballast between the ties being rather loose.

LENGTH OF FLAME.

The flame extended through the full length of the entry (fig. 25). In the cut-through air-course branch it extended 130 feet, but did not pass the Taffanel barrier.

COAL DUST AND COKED DUST.

A thin layer of coal dust and soot was observed in the air course as far out as 36 feet inby the first cut-through. The whitewashed ribs inby this point were very much blackened and coated with dust and soot.

The first two posts of the Taffanel barrier on the east side outby the third cut-through had large crusts of coked dust on the inby side.

The coal was blistered slightly on the north side of the last cut-through.

There was a heavy crust of coked dust on the outby side of the first post on the east side of the entry outby the third cut-through.

A heavy crust of coked dust was found on the outby side of a post at E 658 on the east side of the entry.

A heavy coating of soot covered the shelves inby the third cut-through.

Scattered patches of coked dust were noted on the outby exposures of the coal and posts from E 650 to E 550.

There were crusts of coked dust on the outby sides of posts at E 550 west and E 540 east. There was some coked dust on the outby exposures of the ribs and posts from E 530 to E 440. There was a small deposit of coked dust on the outby side of the shelves at E 350. Slight quantities of coked dust were noted on the outby ends of the shelves at E 250.

ANALYSIS OF AIR SAMPLE.

A sample (No. 2251) of mine air was taken in the last cut-through as soon as it was possible for persons to enter without helmets. The sample was analyzed with results as follows:

CO_2	0.08
O_2	20.85
CO	.00
CH_4	.03
N	79.04

It is to be noted that there was little black damp and no carbon monoxide in the air at the point where this sample was taken, yet the odor had been very irritating.

TEST 15.

Date.—February 24, 1912.

Purpose.—Public exhibition of the explosibility of coal dust and influence of a Taffanel barrier on the advance of the flame from an explosion.

Point of origin of the explosion.—Face of the main entry, E 747.

Method of ignition.—Blown-out shot from a 1½-inch pipe in the coal.

Charge.—Three pounds of FFF black blasting powder, tamped with 5 inches of damp shale dust.

COAL DUST.

Source.—Coal dust was ground from bituminous coal from the Pittsburgh bed, some of which was obtained from the Oak mine, near Pittsburgh, and the remainder from the mine at Willock, Pa.

Size.—Over 95 per cent passed through a 100-mesh sieve.

Analysis.—An analysis (No. 13389) of the coal dust from coal from Oak mine was made with the following results:

Moisture	2.43
Volatile matter	36.73
Fixed carbon	56.16
Ash	4.68
	100.00
Sulphur	.99

Zone.—In entry, E 747 to E 34, or 713 feet; in cut-through 50 feet; in air course, A 654 to A 427, or 227 feet, and A 347 to A 290, or 57 feet; total, 1,047 feet.

Position.—E 747 to E 731 on bench just below the level of the hole containing igniting shot; E 733 to E 34 on permanent side shelves, also on the floor; in cut-through and air course, on floor, and on three transverse "book" shelves.

Quantity.—Two thousand two hundred and thirty-two pounds, or an average of 2.13 pounds per linear foot; equivalent to 0.568 ounce per cubic foot or 568 grams per cubic meter.

Inert zones.—Air course, A 290 to opening; gallery slant.

TAFFANEL BARRIER.

Location.—A 427 to A 347.

Length.—Eighty feet.

Number of shelves.—Thirteen.

Distance between shelves.—Six to seven feet from center to center.

Width of shelves.—Twenty inches.

Thickness of shelves.—One inch.

Depth of stone dust.—Six and one-half inches.

Obstruction.—10.4 per cent of total cross section.

Analysis of stone dust.—

Organic hydrogen	0.39
Organic carbon	7.59
Moisture (at 105° C.)	3.94
Inorganic volatile matter (combined water, CO_2, etc.)	5.42
Ash	82.66
	100.00

VENTILATION AND HUMIDITY READINGS.

Ventilation.—At station E 540, where the cross section was 6 by 9 feet, the velocity of the air was 101 feet per minute, and the volume 5,445 cubic feet per minute.

Humidity readings, test 15.

Station.	Dry bulb.	Wet bulb.	Humidity.
	°*F.*	°*F.*	*Per cent.*
E 50	44½	43	89
E 250	45	43½	89
E 550	44	42	85
Air course	38	36	83

ANALYSIS OF SAMPLE OF AIR.

A sample of air was taken at face of entry just before firing the igniting shot. An analysis was made with the following results:

CO_2	0. 04
O_2	20. 95
CO	. 00
CH_4	Trace.
N	79. 01
	100. 00

INSTRUMENTS AND RECORDS.

MANOMETERS.

Location.—B. C. D. manometer A (suction) at station E 50; B. C. D. manometer B (pressure) at station E 50; B. C. D. manometer C (pressure) at station E 150.

Springs.—Manometers B and C were equipped with springs having a rating of 200 pounds.

PRESSURE CIRCUIT BREAKERS.

Location.—Pressure circuit breakers were installed in all stations from E 50 to E 650, inclusive.

Adjustment.—All pressure circuit breakers were adjusted so as to be operated by a pressure of 3 pounds.

FLAME CIRCUIT BREAKERS.

Type.—Tin foil. (See p. 63.)

Location.—At all stations from E 50 to E 650, inclusive.

SAMPLING BOTTLES.

Two types of sampling bottles were used in this test. The B. C. D. automatic sampling bottle was installed at station E 150, its circuit maker being installed at station E 250. A special sampling bottle was installed in a groove in the rib at E 374.

GUNCOTTON TUFTS.

Guncotton tufts were hung on wires from pegs in the roof at intervals of 25 feet throughout the length of the main entry and the air course.

RECORDS.

Manometers.—Records were obtained on all three manometer cylinders, which are reproduced in figures 26 and 27.

Pressure circuit breakers and flame circuit breakers.—All circuit breakers operated, but on account of the failure of the automatic commutators, records from only four stations were obtained from the pressure circuit breakers and from five stations from the flame circuit breakers. (See figs. 9, 10, and 11.)

Velocity of propagation of explosion, test 15.

Station.	Pressure wave.			Flame.		
	Total time from ignition.	Time between stations.	Velocity between stations.	Total time from ignition.	Time between stations.	Velocity between stations.
	Seconds.	*Seconds.*	*Feet per second.*	*Seconds.*	*Seconds.*	*Feet per second.*
E 650	0.0823			2.174		
		a 0.0878	a 1,139		0.245	408
E 550	.1701			2.419		
		2.095	....		.074	1,351
E 450	2.265			2.493		
		.102	980		.044	2,273
E 350	2.367			2.537		
		....	....		.047	2,128
E 250	....			2.584		
		....	....		....	....
E 150	2.480			....		
		b .125	b 800		....	....
E 50	2.605			....		

a Due to shock from shot. b B. C. D. manometer records.

Sampling bottles.—The pipe of the B. C. D. automatic gas-sampling device at E 150, which projected from the plate to the center of the entry, was broken off at the plate and blown to some other place not known. An automatic gas-sampling device had been set in a recess in the rib at E 370; when the shelves at this point were thrown down, the pipe connection between the bottle and the valve was broken off, and this destroyed the automatic sampling device.

OUTSIDE MANIFESTATIONS.

The first indication of the explosion was the projection of a huge cloud of dust from the opening (Pl. I). When the advancing front of the cloud had reached a point about 100 feet from the opening a spear of flame (fig. 28) from the opening shot into the cloud and disappeared.

There was no manifestation at the other openings except the displacing of the steel sheets on the explosion-door section.

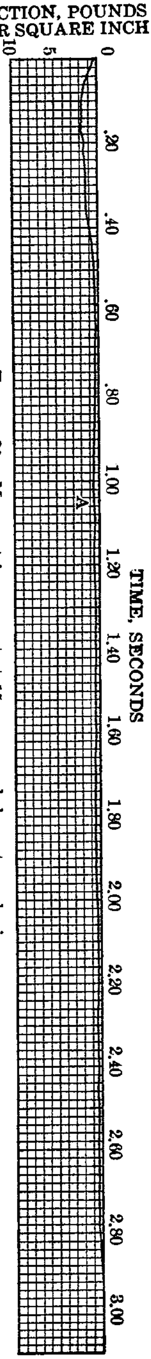


FIGURE 26.—Manometric curve, test 15, pressure below atmospheric.

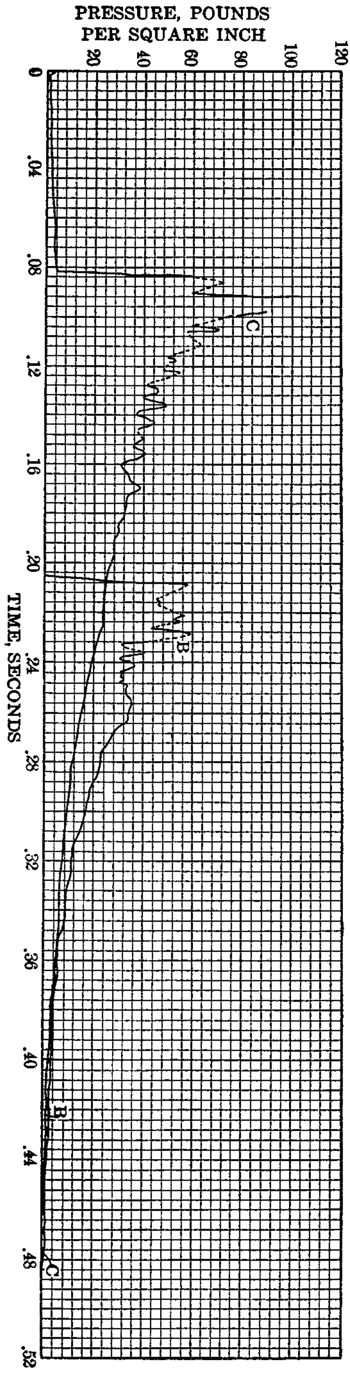


FIGURE 27.—Manometric curves, test 15, pressure above atmospheric.

An empty mine car that had stood on the track 33 feet in front of the opening was blown over the dump and landed in the valley beyond at a point 220 feet distant from its original position (Pl. V, *B*).

The gates at the end of the buttress wall at the main opening were broken and all but the upper portion of the west gate was demolished. The post from which the east gate had been hung, notwithstanding that it was recessed at the end of the buttress wall, was torn from position and carried 33 feet from the opening. All of the lights in the south and west side windows of the pump house were broken outward.

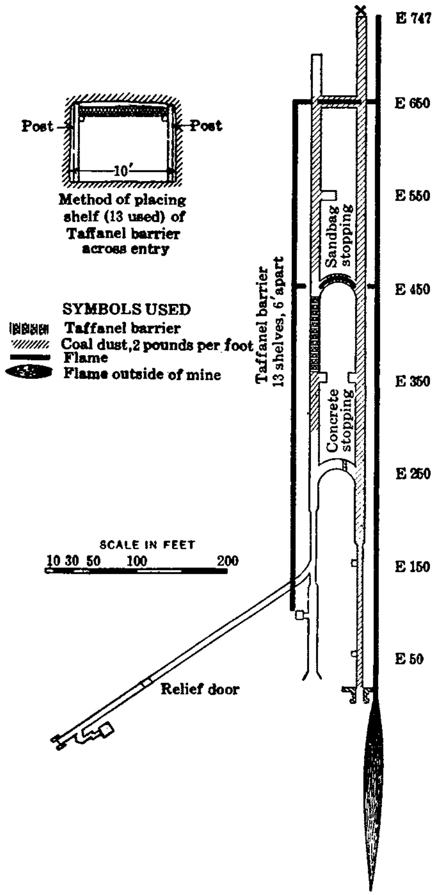


FIG. 28.—Test 15, extent of flame and conditions of test.

INSIDE INDICATIONS OF VIOLENCE.

In the concrete-lined portion of the main entry the same effect was observed after this explosion as had been noted after previous violent explosions, in that the arch of the section had been lifted, the consequent straightening of the vertical reinforcing rods having forced off pieces of concrete lying between these rods and the face of the concrete at the springing line. With one or two exceptions the effect was less than after the explosion of October 30, probably because the concrete had a much more solid backing over the arch, where a large quantity of cement grouting had been run in from the surface through holes. A piece of concrete 30 by 18 inches, with a thickness of from 2 to 3 inches, was forced off at the springing line just over the door at E 50; this piece of concrete was hanging from a ¼-inch round rod in front of the door after the explosion.

At E 61 a ¾-inch square reinforcing rod was buckled by the settling back of the arch, the extent of buckling indicating a raise of at least 3 inches.

At E 77 a crack 1½ inches deep had opened between the original arch and the repair arch put inside the original one after the explosion of October 30. Many of the small cracks caused by the explosion of October 30 were enlarged by this explosion.

The track from E 150 to E 170 seemed to have been raised by the suction following the explosion wave. The ballast was loose and springy throughout this length.

The shelving at the end of the concrete section on the west side of the entry was disarranged by the explosion. The first shelf at the top was broken 2 feet outby the post; the third shelf was broken 5 feet outby the post; and the fourth and fifth shelves were broken loose from the supporting posts at their outby end.

On the east side the third and fifth shelves were unfastened from their supports in the concrete.

Three shelving sets on the east side of the entry extending across the first cut-through were thrown down and moved out of place. The pressure wave seemed to have swept around the inby corner of the cut-through and carried the shelves that extended across the open space against the north rib of the cut-through. When the resulting pressure in the blind cut-through was relieved, a wave swung the shelves of the next set across the main entry and carried the supporting post across to the west rib.

Previous to the test a $\frac{3}{4}$-inch square iron clamp, the ends of which were embedded in concrete in the rib, had held the post inby the cut-through in the groove in the rib. When this post was carried out of the groove the $\frac{3}{4}$-inch bar was broken off where it passed around the post.

The posts and shelves at a dead end opening on the east side of the entry at E 350 were disarranged in like manner to those at E 250. The post on the inby corner was torn out, its clamps broken, and the shelves and post carried across the entry and outby 15 feet.

The sandbag stopping in the second cut-through was partly blown down, the bags of the upper 2 feet of the stopping having been carried in about equal proportion toward the entry and the air course. A cap piece, supported by braces to strengthen the sandbag stopping on the air-course side, was thrown down.

A straw dummy that had been set up at E 650 was torn apart and part of it thrown to the air-course end of third cut-through and another part to E 550.

The igniting charge at the face of the entry had cratered the hole 30 inches back from the front. The front of the hole was 4 feet wide by $4\frac{1}{2}$ feet high.

Some of the temporary track at the face was torn up by the explosion.

The "book" shelves that had been placed at intervals in the third cut-through and the air course were torn to pieces. Only the third, fourth, and seventh posts on the east side of the stone-dust barrier remained standing after the explosion; all the rest of barrier was blown down and the shelves destroyed. The posts and side supports were scattered along the entry for 150 feet outby.

One of the track ties at A 330 was broken at the middle and the east end moved outby. Ties at A 290 and A 281 were also broken in like manner. These breaks were probably due to blows received from the flying posts of the stone-dust barrier.

COAL DUST AND COKED DUST.

No coke or coked dust was noted in the entry from the opening to E 550. Practically all of the coal dust had been swept from the shelves throughout this length, so that the blast was probably too great to allow deposition of coked dust. From E 550 to the face there were increasingly large deposits of soot on the shelves. There was a deposit of coked dust on the outby side of a post at E 648; also heavy deposits on the inby corner of the third cut-through and the entry. At E 656 there were smaller deposits on the inby side of a post on the east side of the entry, and on the outby side of a post on the west side of the entry.

The coal in the entry near the cut-through and through the cut-through had many new blisters. The east rib of the air course opposite the third cut-through and for a short distance outby this point was badly blistered.

In the air course there were still large quantities of coal dust remaining on the floor from A 650 to A 450 but in decreasing amount as A 450 was approached. The coal dust overlaid the shale dust from A 450 to A 350. There was considerable coal dust still remaining on the floor for 75 feet outby this point but very little beyond.

A sample of the coked dust from the inby corner of the main entry and the third cut-through was analyzed with the following results:

Moisture	1.10
Volatile matter	15.40
Fixed carbon	43.19
Ash	40.31
	100.00
Sulphur	1.54

The ratio of volatile matter to fixed carbon shows a large decrease in the percentage of volatile matter over that in the original coal dust.

EFFECT OF BARRIER.

It is not known precisely how far the flame extended beyond the Taffanel barrier. A guncotton tuft 30 feet inby the mouth of the air course was not burned, whereas at 55 feet inby the air-course mouth neither the tuft nor the wire that had held it could be found. The flame had burned the guncotton at a point 80 feet from the mouth, so that the flame must have extended past A 80 but not beyond A 30. Although the barrier did not stop the flame immediately, it had such an effect that the flame extended a much shorter distance than previous experiments indicated it would have gone.

ANALYSES OF GAS SAMPLES TAKEN AFTER THE EXPLOSION.

Two samples of air were taken by a helmet party that entered the mine at the main opening about 15 minutes after the explosion and while the smoke was still issuing.

The analysis of a sample (No. 2249) taken 150 feet inby the main opening showed the following results:

CO_2	1.59
O_2	18.38
CO	1.05
CH_4	.42
N	78.56
	100.00

The analysis of a sample (No. 2250) taken 200 feet inby the main opening showed results as follows:

CO_2	1.47
O_2	18.30
CO	1.08
CH_4	.35
N	78.64
H_2	.16
	100.00

The results of the two analyses are very similar. The oxygen content is high and would be capable of supporting life if no carbon monoxide were present, but the carbon monoxide content is so great that a person not protected by a helmet would retain consciousness only a few minutes in such an atmosphere.

PUBLICATIONS ON MINE ACCIDENTS AND TESTS OF EXPLOSIVES.

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

BULLETIN 10. The use of permissible explosives, by J. J. Rutledge and Clarence Hall. 1912. 34 pp., 5 pls.

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

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

BULLETIN 20. The explosibility of coal dust, by G. S. Rice, with chapters by J. C. W. Frazer, Axel Larsen, Frank Haas, and Carl Scholz. 204 pp., 14 pls. Reprint of United States Geological Survey Bulletin 425.

BULLETIN 44. First national mine-safety demonstration, by H. M. Wilson and A. H. Fay, with a chapter on the explosion at the experimental mine, by G. S. Rice. 1912. 75 pp., 7 pls.

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

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

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

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

TECHNICAL PAPER 6. The rate of burning of fuse as influenced by temperature and pressure, by W. O. Snelling and W. C. Cope. 1912. 28 pp.

TECHNICAL PAPER 7. Investigations of fuse and miners' squibs, by Clarence Hall and S. P. Howell. 1912. 19 pp.

TECHNICAL PAPER 11. The use of mice and birds for detecting carbon monoxide after mine fires and explosions, by G. A. Burrell. 1912. 15 pp.

TECHNICAL PAPER 12. The behavior of nitroglycerin when heated, by W. O. Snelling and C. G. Storm. 1912. 14 pp., 1 pl.

TECHNICAL PAPER 13. Gas analysis as an aid in fighting mine fires, by G. A. Burrell and F. M. Seibert. 1912. 16 pp.

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

TECHNICAL PAPER 18. Magazines and thaw houses for explosives, by Clarence Hall and S. P. Howell. 1912. 34 pp., 1 pl.

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