Bulletin 268

DEPARTMENT OF COMMERCE
HERBERT HOOVER, SECRETARY

BUREAU OF MINES
SCOTT TURNER, DIRECTOR

COAL-DUST EXPLOSION TESTS IN THE EXPERIMENTAL MINE 1919 TO 1924, INCLUSIVE

BY

GEORGE S. RICE, J. W. PAUL, and H. P. GREENWALD

PRICE 35 CENTS
Sold only by the Superintendent of Documents, Government Printing Office
Washington, D. C.

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON
1927

CONTENTS

ILLUSTRATIONS

PREFACE

This report on the third series [1] of coal-dust explosibility tests at the experimental mine near Bruceton, Pa., about 12 miles fom the Pittsburgh experiment station of the bureau, covers the years 1919 to 1924, inclusive.

SUSPENSION OF TESTS

The previous testing of dusts to determine their explosibility was suspended in 1918, during the World War, in order to allow the bureau to take up a series of problems dealing with military mining, sound ranging, and tests of explosives, including experimental work with liquid-oxygen explosives. Another problem investigated was the possibility of storing helium gas under high pressure, up to 100 atmospheres, in mine chambers, lined and unlined, instead of in metal bottles. To make such chambers gas-tight, even when lined with copper and with lead sheets, proved difficult because of the elasticity of the walls.

After the war the mine had to be used for special purposes. The most important purpose was to test the effectiveness and limitations of a novel method of ventilating an underground tunnel in which internal-combustion motors—automobiles and trucks—are used. The immediate application of the results was to be in the proposed Holland vehicular tunnels under the Hudson River, and the study was undertaken at the request of State officials of New Jersey and New York. The investigation obtained fundamental data on the amount of poisonous gases given off by automobiles and trucks, the physiological effects of those gases, the necessary limits for ventilation, and the adequacy of the proposed system of ventilation and its possible application in mining. A report [2] was rendered to the New York-New Jersey Bridge and Tunnel Commission.

Then, to take advantage of the set-up of delicate gauges for recording air flow and pressure, a series of experiments was made in order to determine frictional losses in the ventilation of coal mines, under various conditions and arrangements.[3]

---

[1] The first series, comprising preliminary tests and demonstration, was reported in Bulletin 56, which also described the construction of the experimental mine, the recording stations, and instruments. Bulletin 56 covered the period between the opening of the mine in 1910 and the close of 1912. The second series of tests was reported in Bulletin 167, which covered the years 1913 to 1918, inclusive.

[2] The report was not published by the bureau, but part of it was published in Appendix 3, Report of New York State Bridge and Tunnel Commission, 1921, pp. 81–140. A paper covering the ventilation testing work for the Holland tunnels and later work for the Liberty tunnels at Pittsburgh is being published by the American Society of Heating and Ventilating Engineers.

[3] Paul, J. W., McElroy, G. E., and Greenwald, H. P., The Resistance of Coal-Mine Entries to the Flow of Air: Repts. of Investigations, Serials 2621, 2647, and 2671, Bureau of Mines, July, 1924. A bulletin will follow.

Another phase of the investigation started in connection with the tunnel work was a study of the flow of heat from the natural walls, roof, sides, and floor into the air current and vice versa, a problem of much importance in ventilation of deep or hot mines. A report on this investigation is to be published.

Thus, the testing of coal dust was again suspended in 1921 to 1923. Meanwhile, the number of explosion disasters in coal mines in this country had steadily diminished; in 1918 explosions killed 41 men, in 1919 they killed 81, in 1920 but 47, and in 1921 only 16, as contrasted with about 2,000 men killed each year in coal mines by falls of roof, haulage, and other underground accidents.

This reduction in the number of men killed by explosion disasters[3a] as compared with 882 killed from this cause in a single year (1907) seemed to indicate that the danger of these disasters had been overcome.

Apparently, however, this reduction was a matter of coincidence. Disastrous coal-dust explosions began to recur in the bituminous mines of the country. In 1921 explosions killed 264 men, in 1923 they killed 286, and in 1924, 445, the largest number killed in coal-dust explosions since 1907.

RESUMPTION OF ACTIVITIES

This increase naturally aroused great anxiety in the coal-mining industry. It raised the question why the recommendations of the bureau for rock dusting had not been accepted and followed in this country as similar recommendations by Government agencies in Great Britain and in France had been followed in those countries. In Great Britain the recommendations were made mandatory; in France most of the mines adopted rock dusting after the Government had approved it, and Government pressure was being put on the others.

In 1923 the senior author of this bulletin was sent abroad to examine the methods of rock dusting used in Great Britain, France, and Germany. His report was issued as Bulletin 225.[4]

Meanwhile, testing of coal dusts was resumed at the experimental mine, especially tests for determining the relative explosion hazards of coal dusts from various typical mines by the procedure laid down in Bulletin 167.[5]

Later the Bureau of Mines, at the request of the British Mines Department, entered into a cooperative agreement with the British Safety in Mines Research Board for joint research in mine safety, including coal-dust explosion investigations. The British Govern-

---

[3a] Five or more fatalities in each.

[4] Rice, G. S., Stone Dusting or Rock Dusting to Prevent Coal-Dust Explosions: Bull. 225, Bureau of Mines, 1924, 57 pp.

[5] Rice, G. S., Jones, L. M., Egy, W. L., and Greenwald, H. P., Coal-Dust Explosion Tests in the Experimental Mine, 1913 to 1918, inclusive: Bull. 167, Bureau of Mines, 1922, p. 218 and following.

ment sent Dr. R. V. Wheeler, director of research, his assistant, W. R. Chapman, and Henry Walker, then deputy chief, and later H. M. chief inspector of mines, to the United States in the spring of 1924 to arrange with the bureau officials a joint program of work. Later the director of the Bureau of Mines, H. Foster Bain, visited England on the same mission. While here the British representatives witnessed tests of the Silkstone (Yorkshire) coal dust, used at the Eskmeals station as the British standard dust for testing. They also greatly advanced the cause of rock dusting in the bituminous mines of this country by attending numerous meetings of mining men, where they explained the success that had followed compulsory rock dusting or "stone" dusting in Great Britain.

The Bureau of Mines sent the junior author, H. P. Greenwald, assistant physicist, to the British testing station at Eskmeals, where Doctor Wheeler placed him in charge of a group of coal-dust tests of English coals in the main explosion gallery. While there he conducted tests to compare the Pittsburgh standard dust used at the bureau's experimental mine with the Silkstone dust used as standard at Eskmeals. The results of these comparative tests showed that the British standard coal dust behaves essentially like the American standard dust from the experimental mine, thus confirming results of similar comparative tests made in that mine.

It is expected that the agreement with the British station, which provides for interchange of personnel, materials, and instruments, and for prompt interchange of information on the progress of the different lines of research, will be stimulating to both sides, prevent unnecessary duplication, provide standards for comparison, and greatly advance knowledge of preventive measures.

FACTORS DEVELOPED BY NEW SERIES OF TESTS

The series of explosion tests covered by this bulletin has not developed any strikingly new fundamental facts. The results of the tests largely confirm those reported in Bulletin 167, but more precise information has been obtained on the underlying factors that govern coal-dust explosions, particularly in regard to the effect of the size of dust particles on their relative explosibility in air and the great influence of fire damp in increasing the explosibility of dust mixtures. Although fire damp increases the sensitiveness of all coal dusts to ignition and propagation, it has the most marked effect on the low-volatile coal dusts and on coarse coal dusts, which are not so explosive when it is absent.

Some additional data were obtained on the effect in the starting and propagation of an explosion, of release of pressure, both near the point of origin and at a distance along the path, but much remains to be done in studying the mechanism of explosions.

The wide adoption of the rock-dusting method by American mine operators since the campaign inaugurated by the bureau in 1923 has led to a stream of inquiries from mining men, State officials, and liability insurance rating bureaus regarding rock dust and its application. Accordingly, the bureau issued Serial 2606,[6] containing the specifications for rock dusting. Appended to this bulletin is the schedule on rock-dusting practice approved by the American Engineering Standards Committee; it accords with the specifications in Serial 2606.

Special conditions in various coal fields call for special rock-dust treatment, and a need has developed for rock-dust barriers where generalized dusting is considered impracticable. The staff of the experimental mine is now engaged in carrying on special experiments and tests of barriers with a view to formulating specifications for "recommended" barriers.

Since the issuance of Bulletin 167 the Government has acquired the coal and surface contiguous to the mine, thus assuring the permanence of the mine and securing from loss the large investment in the mine and the permanent apparatus that would be practically valueless if the mine were not retained.

Although some extensions were made within the experimental mine, chiefly to provide for other testing, the standard arrangements for explosibility testing have not been changed.

ORGANIZATION AND ACKNOWLEDGMENTS

The whole scheme of test work in the experimental mine has been from the beginning under the general direction of the senior author, George S. Rice, chief mining engineer. Since 1917 the direct supervision has been in charge of J. W. Paul, chief of coal-mine investigations. The details of the tests of explosibility of coal dust were handled by H. P. Greenwald, assistant physicist, and H. C. Howarth, superintendent. Greenwald has charge of the scientific instruments and interprets the results of the tests; he prepared the descriptions and interpretations herein in conference with the senior authors. Howarth supervised all miners and laborers, and the preparation of material for specified tests. He assisted in the tests and in obtaining the records of physical conditions after each test explosion that are incorporated in this report. The admirable manner in which he has kept the mine in condition for all tests and experimental work has permitted reliable records to be obtained whose consistency is remarkable in view of the complicated nature of the explosion tests.

Without precise chemical analyses of coal dusts and gases before and after explosion tests it would be impossible to carry on the investigation. A. C. Fieldner, supervising chemist and superintendent of

[6] Rice, G. S., Paul, J. W., and Sayers, R. R., Tentative Specifications for Rock Dusting to Prevent Coal-Dust Explosions in Mines: Repts. of Investigations Serial 2606, Bureau of Mines, May, 1924.

the Pittsburgh experiment station, and his staff have not only carried on the chemical work admirably, but have greatly assisted by their advice. V. C. Allison, assistant chemist, who is on the experimental mine staff, has assisted in the instrument work and records of the mine, besides making laboratory explosion investigations in a steel gallery.

Many other persons contributed to other kinds of investigations such as the ventilation work; acknowledgment for this assistance will appear in the appropriate special reports.

George S. Rice,
Chief Mining Engineer.

COAL-DUST EXPLOSION TESTS IN THE EXPERIMENTAL MINE 1919 TO 1924, INCLUSIVE

By George S. Rice, J. W. Paul, and H. P. Greenwald

INTRODUCTION AND SUMMARY

This bulletin describes the third series of coal-dust explosion tests by the Bureau of Mines in its experimental mine and covers a period from 1919 to the end of 1924, inclusive. A few related tests made in 1925 are also included.

The first series was reported in Bulletin 56,[7] which dealt with tests to determine the conditions under which explosions could be started.

The second series was reported in Bulletin 167,[8] which (1) contained a historical review of literature on the explosibility of coal dust, including previous publications issued by the Bureau of Mines on the subject, and (2) dealt with the control of factors in the ignition and propagation of coal-dust explosions, and the development of methods and apparatus for determining the physical accompaniments of explosions. These include the velocity and duration of the flame, the nature and duration of the pressure waves, and the movements of the air and gas before, during, and after an explosion. The development of chronographs, manometers, samplers, and other instruments for this work was traced. A wide series of tests was reported covering the inefficiency of dustless and wet zones in limiting coal-dust explosions and also the explosibility of merely dampened coal dust, both in the absence of gas (fire damp) and with gas present in varying amounts up to 3 per cent. Tests were made of the conditions under which rock dust may be used to control and prevent coal-dust explosions, either in barriers or by broadcasting. The development and testing of different types of barriers were recorded in detail, and the few failures and much larger number of successes during this work were summarized.

The successive steps leading to the standardization of methods of testing were traced. Also, sections of the bulletin were devoted to

---

[7] Rice, G. S., and others, First Series of Coal-Dust Explosion Tests in the Experimental Mine: Bull. 56, Bureau of Mines, 1913, 115 pp.

[8] Rice, G. S., and others, Coal-Dust Explosion Tests in the Experimental Mine, 1913 to 1918: Bull. 167, Bureau of Mines, 1922, 639 pp.

the relative inflammability of dust from different coals, particular attention being paid to the relation of explosibility to the ratio of volatile combustible and fixed carbon, and the effect of size of dust on explosibility.

The method of determining the percentage of inert dust required to prevent propagation of an explosion was developed as a criterion for judging the relative inflammability of different coals, as a substitute for the use of the relative pressures obtained in explosions, as employed in some prior European testing.

After the standard tests for ignition and propagation were developed a plan was worked out for testing the explosion hazard of an individual mine. Methods of sampling coal and road dusts were evolved in order that information on the size and composition of the dusts in the mine under investigation would be available when explosion tests were made of a large sample of coal obtained from the mine. In making these explosion-hazard investigations of operating mines, typical mines in different fields were selected in order to cover as well as possible the principal variations in compositions and character of coals mined in the developed coal districts of the United States. The results were reported direct to the respective mine managements, with recommendations designed to lessen the hazard of explosions.

A preliminary series of tests in the left butt entries of the experimental mine was undertaken to determine how the development of a coal-dust explosion is affected by openings into rooms, by right-angle turns, and by weak and strong stoppings.

CHANGES AT THE EXPERIMENTAL MINE

The surface plant at the experimental mine is described in Bulletin 167,[9] except that in 1923 purchased electric power for all purposes was substituted for steam power.[10]

Since 1918 the underground workings (see fig. 3) have been extended as coal was needed for fuel. Left entries 1 and 2 were driven a total length of 525 feet from the main air course, and rooms 1 to 5 were extended to their full length of 200 feet. Room 6 was also started and driven 200 feet. In order to prevent any additional openings into left entry 1, rooms 7 and 8 were developed from room 6 and driven toward left entry 1, but have not been broken into it. Rooms 1, 2, and 3 were utilized during 1921–22 for the construction of an experimental vehicular tunnel. In this tunnel tests were made of exhaust gases from automobiles to determine the effectiveness and safety of the transverse method of ventilation which had tentatively

[9] Bulletin 167 will be referred to in the text throughout in order to save many footnote references.

[10] Details of the conversion of steam to electric power are given in a 100-page thesis written and submitted by H. P. Greenwald to the Carnegie Institute of Technology, Pittsburgh, Pa., 1923.

been recommended by the bureau and was confirmed by these tests for the Holland vehicular tunnels now being constructed under the Hudson River.[11] Upon completion of the ventilation tests these rooms were sealed so that in future explosion tests they would be entirely cut off from communication with the remainder of the mine.

Except in minor details the recording instruments have undergone no changes. Additional flame-velocity recording plugs have been provided and may be installed at any point within the mine at a minimum of expense.

In order to obtain data on air and gas velocities set up by explosions, an instrument has been designed by H. P. Greenwald which is modeled after the principle of the air-direction indicator but has a revolving drum with sensitized film; on this film a continuous record may be obtained by the movement of a mirror that reflects a beam of light.

Four type C automatic gas samplers extending 27 inches from the rib were installed at E 950 (see fig. 3) in order to sample the central explosion zone. One was also used at E 1280, which is within the ignition zone.

The use of guncotton tufts to supplement manometer records of the passage of flame was abandoned, and matches are used in restricted numbers to give an approximation of the passage of flame; the main reliance for flame records, however, is on the sensitized photographic paper inclosed in plugs placed in the roof.

SUMMARY OF RESULTS

COMPOSITION OF PRODUCTS OF COMBUSTION

The progress of explosive combustion has been studied by collecting samples of gas in advance, at the time, and after the passage of the flame, thus carrying forward similar work reported in Bulletin 167. The analyses from these tests show, as had been previously surmised, that, at the moment of explosion and for a short time following the passage of the flame, the products of combustion near the center of the entry differ widely in composition from those near the sides or walls, and that combustion is much more complete (or the oxygen has been more completely combined) near the center than at the side or rib. The analyses also show that in explosions having low flame velocities (200 feet per second or less), combustion is not so complete, near either the center or the sides, as in explosions having high velocities. In explosions of high velocities (500 feet per second or more), there is no free oxygen present in the gases near the center, and any

[11] This work was carried out in cooperation with the New York-New Jersey State Bridge and Tunnel Commissions; the reports rendered to the commission have been published in brief outline in the annual reports of the commission and to some extent in technical journals. (See Appendix 3, Report of New York State Bridge and Tunnel Commission, 1921, pp. 91-140.)

excess or unburned coal dust may be distilled, giving hydrogen, methane, and possibly ethane, with as much as 5 to 10 per cent carbon monoxide, and in violent explosions, ethylene.

DUPLICATE TESTS

In order to be assured that the conditions and methods of testing do not vary from year to year and to check the results of previous tests about which there may have been some question, a few tests were made which duplicated those of previous years. The general uniformity of these duplicate tests and their agreement with previous tests are very striking.

In these additional tests it was found that with no coal dust in the ignition zone the flame of the cannon shot of 4 pounds of black blasting powder was 25 feet long, as previously determined; and with 50 feet of pulverized Pittsburgh coal dust in the ignition zone, the flame extended 50 feet into the dustless zone, or 100 feet from the cannon. Pittsburgh coal dust (all through 20-mesh) was found to be more explosive in one test where the percentage of 48 and 100 mesh dust was increased, the 200-mesh content remaining constant at 20 per cent. This, if supported by future testing, may indicate the need of a more complete standard of dust fineness than simply the percentage of 200-mesh. It has been assumed, from the results of numerous experiments, that when different coals are crushed to pass through a 20-mesh sieve, the percentages passing through the finer screens would be approximately the same and measurably independent of the kind of coal. Further investigation of this question is needed.

TESTS OF VARIOUS COAL DUSTS

The testing of coal dust prepared from samples of coal shipped to the experimental mine from producing mines was the principal explosibility problem in hand from 1919 to 1924. The tests were conducted as a part of the explosion-hazard investigation of the mines from which the samples were taken.

The dust from these samples was so prepared that it had as nearly as possible the same fineness as the average size of dust found in the mine from which the coal came. The samples of road dust from a majority of the mines show an average of less than 20 per cent through 200-mesh, while the rib and roof dust average 40 to 50 per cent through 200-mesh, and dust on timbers runs as high as 85 per cent through 200-mesh. An average of the sizes of all dust from the road, rib, and roof in proportion to the weights present usually shows that a little more than 20 per cent passes through 200-mesh, but in some places in a mine there is often enough dust on the rib, roof, and timbers to propagate an explosion; this dust is frequently dry, although the dust on the roadways near by may be damp or even wet. Samples of dust from 13 different mines were tested to determine the amount of inert rock dust needed for the prevention of ignition and propagation. Details of the tests are given later in this report.

EFFECT OF ROOMS ON DEVELOPMENT OF EXPLOSIONS

The schedule of tests in the first and second left entries, to which extended reference was made in the report on the second series (Bulletin 167), was resumed during the period covered by this present bulletin. The left entries were extended to a total distance of 525 feet from the main air course, and during 1920 a series of 20 tests were made under the new physical conditions of these entries.

Previous testing had shown that explosions could not be produced in these left entries as easily as in the main entries, probably on account of the rooms, which afford relief to the pressure. The tests herein recorded support the theory that loss of pressure into rooms that were not charged with coal dust is undoubtedly the cause of the slowing up of the earlier explosions.

In a later test the pressure built up to 36 pounds per square inch at a point 275 feet from the cannon, whereas in a similar earlier test the pressure was 13 pounds at 300 feet from the cannon, but in the test showing the higher pressure the explosion traveled a longer distance before passing a room neck. These tests, however, were made without coal dust in the rooms, and the effects of placing coal dust in such amounts as are usually found at the entrances of and within rooms remain to be determined. The results of these tests indicate that, if there were no rooms on the side entries, the pressure would build up in the same manner as in the main entries.

Tests in these left entries where coal dust, 10 per cent of which passed 200 mesh, was used brought out important data on the action of explosions in room entries with open cut-throughs and shed some light on the behavior of explosions in producing mines as to the relative position of coked dust and of loose or movable objects with respect to origin. In these tests, as recorded by the instruments, it is evident that the explosion wave, while advancing with respect to the explosive media, at times may be retreating with respect to fixed points of the mine entry, confirming previous observations in the main entries.

The series of tests of the effect of stoppings in cut-throughs, reported in Bulletin 167, were continued. It was found that an explosion will travel the entire length of both left entries, whether no stoppings, weak stoppings, or strong stoppings are used in the cut-throughs or crosscuts. When strong stoppings were used which withstood the pressure, the explosibility limit as determined by the percentage of inert dust required to prevent propagation was increased. However, any stopping strong enough to withstand the air shocks of ordinary mine blasting will not fail from a weak explosion, and the failure of a stopping does not affect a violent explosion enough to check its progress, especially if there is coal dust in the crosscut.

IMPROVEMENT IN ROCK-DUST BARRIERS

The work on various types of rock-dust barriers, brought out in previous publications of the bureau, has borne some results in that officials of commercial mines have developed models which would be cheaper in construction than the models developed by the senior author and found efficient in stopping explosions in the experimental mine. However, in the models developed at commercial mines some of the important requirements have been overlooked, such as sensitiveness to weak explosions, rapidity of discharge, quantity of material held, etc. The Bureau of Mines' facilities were opportunely of value in testing a concentrated barrier submitted by one company. The barrier failed in the original form but met the requirements after being modified as a result of the tests. Also, tests of small V-shaped troughs were made and their limitations of use were determined, both in capacity and method of operation and discharge. Most of these small troughs, however, failed in the tests in the experimental mine by reason of their lack of capacity and failure to discharge their contents over a period of time.

The concentrated barrier, designated as the "Rice barrier," underwent additional trials in the testing of coal dusts, and at all times showed its efficiency and reliability in stopping all explosions where it was used.

The Taffanel barrier was subjected to additional tests and met many of the requirements, but was not so dependable for weak explosions.

Further experiments were made with rock-dust zones as a substitute for concentrated barriers. Their efficacy for stopping strong explosions is questionable unless they are so extensive as to be equivalent to general rock dusting. However, further investigations of the use of cross shelves to supplement general rock dusting are needed.

Questions concerning the use of barriers, their proper design, construction, and installation have become very pressing. Their application has been widespread, both to supplement and to replace general rock dusting.[11a] They have a certain sphere of usefulness and when properly designed and installed are thoroughly reliable. It has been the impression of the authors after inspection in various

[11a] "General rock dusting," as used in this report, means broadcasting rock dust.

commercial mines that many of the installations recently made have certain features which may render them of doubtful value at a time when everything depends on their proper operation. Barrier testing was a minor issue during the period covered by the present bulletin, but the sudden development and use of many untested designs has made desirable further experiments to devise standard tests that can be applied to any barrier to determine its efficiency. These tests will be reported in a separate publication, therefore no detailed results of barrier testing are given in this bulletin.

FUTURE INVESTIGATIONS

A number of problems which have an important bearing on coal-mine explosions were outlined on pages 10, 11, and 12 of Bulletin 167. Some have since been studied. Some of the most urgent that remain to be studied are—

1. The determination of the quantity and character of coal dust and the number and character of shots required to initiate an explosion in wide places, such as rooms.
2. The retarding effect of the presence of rock dust in room necks and in break-throughs upon an explosion started in the room entry.
3. The relation of bends and turns to the progress of an explosion.
4. Comparison of the explosibility of coal dust collected from a producing mine with that of coal dust prepared mechanically from samples of coal taken from the same mine.
5. The determination of the manner in which natural gas or methane and air mixtures explode and propagate.
6. The influence of the presence of rock dust on a gas and air explosion.
7. Completion of a series of tests with Pittsburgh coal dust to determine the length of flame in both ignition and propagation tests with varying mixtures of coal dust and rock dust in increments of 10 per cent, and near the critical line in increments of 5 per cent.
8. Determination of the effect of increased length of the ignition zone or of placing the ignition zone at some point removed from the face of the entry.
9. Determination of the effect of varying the size of the charge in the cannon.
10. Obtaining samples of air simultaneously at different points from the rib to the center of the entry before and during the progress of an explosion, in order to determine the character of products of combustion and the progress of chemical reactions at different points.
11. Testing of additional coal dusts, as part of the explosion-hazard investigations of producing mines.
12. Further testing of the effect of a film of more or less pure coal dust on top of rock dust, such as may be found after rock-dust treatment in a producing mine.
13. Effect of fine pure coal dust on timbers or cross shelves when the ribs and floor are well rock dusted.
14. Effect of pure coal dust in quantity on the trackway when the walls, timbers, and parts of floor are well rock dusted.
15. Trial of different inert dusts for barriers with a view to obtaining materials that do not absorb moisture and become wet, making the rock dust valueless. A special demand has arisen for dusts of this type in mines where watering is used with mining machines at the coal face and elsewhere as may be required

by State regulation, as in Utah. Such methods cause the return air to be very humid.

16. Development of a method of standardized testing of barriers to determine the efficiency of operation of special barriers submitted for testing by mining companies or by manufacturers.

17. Investigation of the effect of watering the roadway in addition to rock dusting the ribs and timbers, as practiced in some mines.

DEVELOPMENT OF EXPERIMENTAL MINE AND EQUIPMENT FROM 1919 TO 1924

The surface plant, underground workings, and testing equipment of the experimental mine as they existed in 1918 were described in detail in Chapter II of Bulletin 167 and illustrated in Figure 1 of that bulletin, reproduced as Figure 1 here.

It is the purpose of the present section to detail only those changes made since 1918.

PURCHASE OF PROPERTY

The experimental mine was originally developed on land and in coal leased from the Pittsburgh Coal Co. The growth in the number of surface buildings and the extensions and installations in the underground workings required by the testing have led to a large investment in the property by the Government. It has become an institution of the greatest value to the coal-mining industry, and the results of its tests have carried conviction in other countries, as well as in the United States. Continuance of the work since 1911 has depended on extensions of short-term leases of surface and coal. In addition to the experimental work on the explosibility of coal dust and gas, the explosives-testing work was moved during the summer and fall of 1918 from Pittsburgh to a plot adjoining the experimental mine. There was a continuously growing investment in mine development and equipment, most of it immovable. The necessity of owning the property under these conditions was recognized, and the matter was laid before Congress late in 1922. Favorable action was taken; purchase and transfer of the property to the United States was made in the spring of 1924. In buying the property the question of future expansion and the liability of damage to adjacent property from explosions was kept in mind, and the tract purchased consisted of slightly more than 72 acres of surface and 39 acres of coal. On the east the property extends to the railroad and the highway, while on the west it extends to a line 500 feet beyond the large powder magazine belonging to the explosives-testing plant of the Bureau of Mines. On the north and south the property extends to the top of the hills bordering the ravine, along which are the surface buildings. Figure 2 is a plan of the surface and coal obtained. The coal purchased included everything from the mine entries east to the crop line, except a small area under

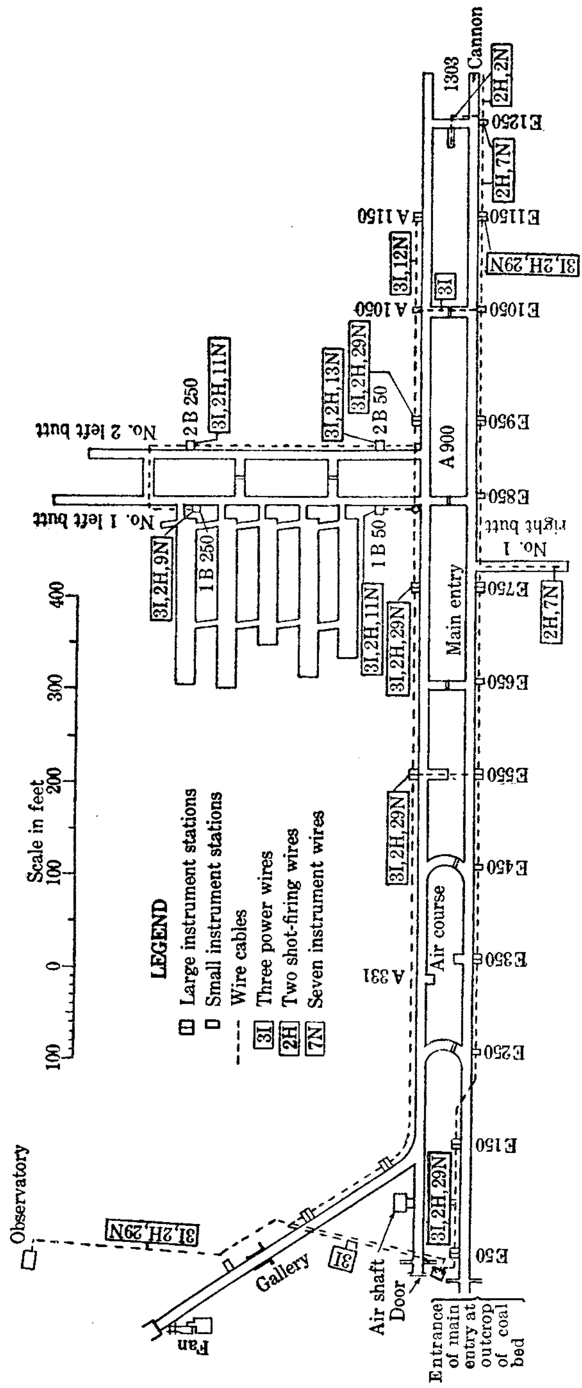

FIGURE 1.—Diagram of experimental mine, observatory, stations, wiring, and development, as of June, 1919

some farm buildings close to the southern boundary. West of the mine workings only enough coal was purchased to form a barrier pillar for protecting Montour No. 10 mine of the Pittsburgh Coal Co., whose workings were rapidly approaching the experimental mine. The coal under the surface used by the explosives-testing plant was also purchased, in order to prevent any damage to the equipment through subsidence.

SURFACE PLANT

The only important change in the surface plant from 1918 to 1924 was the abandonment of steam power and substitution of purchased electric power. The failing local water supply and the increased demands for power, together with the necessity of cheaper operation, made some action necessary. After careful study the economies made possible by the conversion were so evident that the plan was adopted in 1922. Central station power had become possible only two years before, when a high-tension line was constructed through Bruceton, 1 mile from the mine. Alternating-current motors were selected to drive the fan, grinding-house machinery, air compressor, and other small machinery. The direct current for the instruments was supplied through a motor-generator set. This change resulted in much more economical and satisfactory operation during testing work, and made possible the obtaining of test data that could not be gotten with the former limited capacity of electric-power equipment.

UNDERGROUND WORKINGS AND EQUIPMENT

The underground workings were extended from time to time to meet certain test requirements and to provide coal for the boilers. Left entries 1 and 2 were extended during 1919 to a length of 525 feet from the air course, cut-throughs connecting them being driven at points 400 and 475 feet from the air course. This is as far as these entries can be driven on account of decreasing cover; the plan is to turn a pair of entries at right angles to the left after extending No. 2 left 50 feet further. Figure 2 shows the relation of the left entries to the boundary line of the coal purchased. Figure 3 shows on a larger scale the mine workings as they were on December 1, 1924. The mining of coal for the boilers had increased the area of the rooms. Rooms 1 to 5 were all extended to a length of 200 feet, then room 6 was started and driven to the same length. For testing work it was desired not to have any more openings on No. 1 left, so rooms 7 and 8 were started from a crosscut at the face of No. 6 and driven toward No. 1 left as shown in Figure 3.

In extending the left entries a local depression of about 2 feet in the coal bed was encountered with some small clay veins and water. It became necessary to blast a sump at the face of No. 1 left and pump the water regularly. The quantity is not large but the flow is steady, and if not pumped would fill up the depression until it overflowed out the air course.

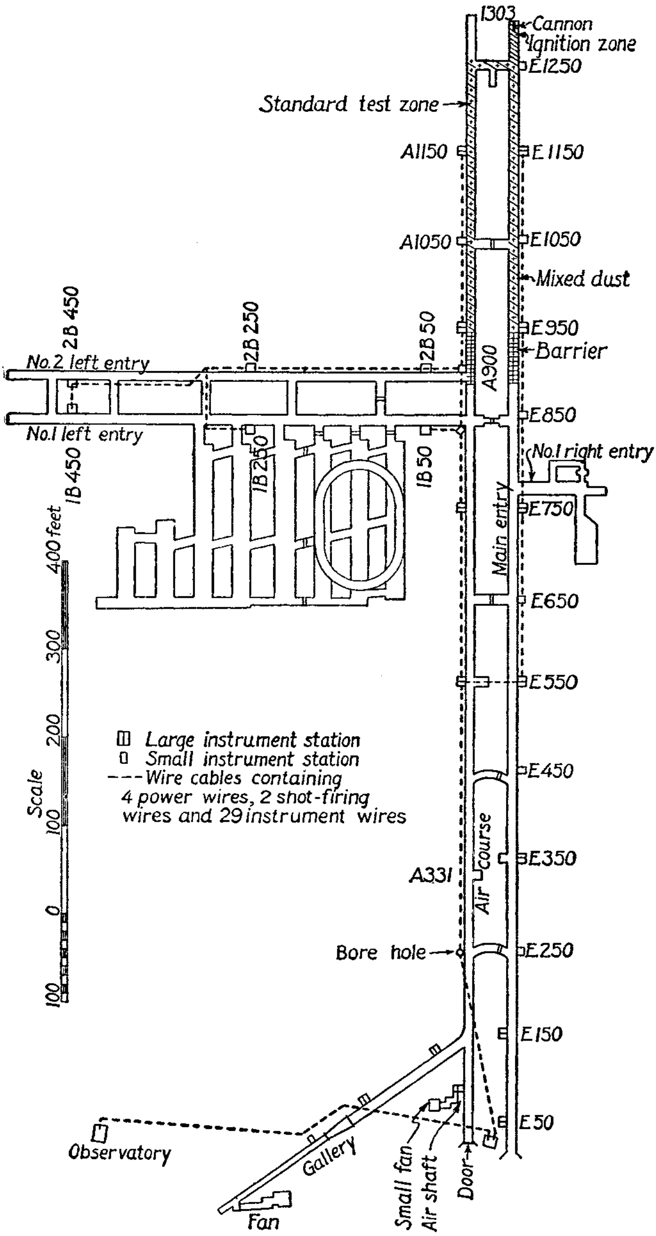

FIGURE 3.—Diagram of experimental mine, observatory, stations, wiring, and development as of December, 1924, showing extent and arrangement of standard test zone

As already mentioned, in 1921 an agreement was entered into with the New York and New Jersey Tunnel and Bridge Commissions to test tunnel ventilation in order to check the design of the proposed transverse sectional ventilating system for the Holland vehicular tunnels now being built under the Hudson River at New York.[12] A model of the vehicular tunnel about one-third scale in cross section and elliptical in plan was constructed in rooms 1, 2, and 3, enabling automobiles to run continuously one behind another. In order to get the desired height, about 10 feet of the roof was taken down along the course of the tunnel. In the upper part a great deal of water was encountered, requiring regular pumping from this section. After the tests of the tunnel an investigation of coal-mine ventilation factors was started, and no coal-dust explosion tests were run until December, 1923. Before explosion testing was resumed heavy bulkheads were constructed across all entrances to the vehicular test tunnel to protect it from violence. This reduced the area of rooms which could take part in an explosion, making the results more comparable with previous tests involving rooms.

While the ventilation tests were being conducted, coal for boiler fuel was obtained from a room driven off right entry 1. A special side passage was also driven off this entry in order to provide a place for conducting some tests of the strength of mine stoppings in explosions.[13]

As the left entries would in time be advanced toward an old wagon mine near the farm buildings on the south crop line of the purchased coal, this old mine, which had not been worked for at least 25 years, was opened, drained, surveyed, and mapped. The workings proved to be more extensive than had been anticipated, and will somewhat affect future extension of the experimental mine in that direction. Figure 2 shows the map.

WIRING SYSTEM

The instrument wiring as of 1918 was described in Bulletin 167, page 37. This wiring deteriorated steadily, and in the winter of 1923–24 trouble was experienced from complete failure of the insulation at some points, as water gathered in the conduits. An extensive replacement was made in the summer of 1924, and the arrangements were completely changed near the mouth of the mine, as comparison of Figures 1 and 3 will show. The new instrument cables were taken above ground from the safety switch box near the pit mouth to a bore hole which entered the air course about 250 feet from the mouth. They then continued in the regular conduit to station A 550 where a branch was taken off to serve the entry stations from E 550 inby. The cables continue inby on the air course

---

[12] An outline of the work is given in Appendix 3, Report of New York State Bridge and Tunnel Commission, 1921, pp. 91–140.

[13] To be reported in a publication of the bureau when testing is completed.

to A 1150 with branches to serve the stations in the left entries. Extensions to other points, such as the face of an entry, are made with single or duplex wires, as may be desirable, and are not shown on Figure 3.

The new 31-wire cable that serves the chronographs is a replica of the old, as the failures in it had been caused more by improper installation than poor cable design. What had been designed as an installation to last 3 or 4 years had actually been in service 10 years under adverse conditions, and better conduits were needed rather than better cable.

The growth of the work had made the old three-wire cable inadequate, and the new power cable contained two No. 10 and two No. 4 wires. The larger wires carry power for the instrument motors and manometer lamps and the smaller carry current for general lighting purposes in the stations. It was desirable to separate these circuits entirely so that A. C. lighting service could be maintained in the interval between tests when the motor-generator set was not needed. Maintaining light continuously gives a slight elevation of temperature in the station, which prevents condensation of moisture on the instruments.

Inspection of Figure 3 will show that when the instrument stations were installed at 2 B 450 and 1 B 450 in 1920 they were placed back to back in the chain pillar. It is the intention to construct all future stations in this manner to reduce the amount of wiring, as the cables can then be carried up one entry to a station, then through a bore hole in the coal to the station on the opposite entry, continuing from there up the second entry to the next station, and so on.

When the conversion to purchased electric power was accomplished, a bore hole was sunk from the surface at the face of room 6 and a line of No. 00 wire was carried into the mine through it. This line carries power for operating an electric mining machine[14] and an electrically driven pump for unwatering the test tunnel and the faces of No. 1 left and room 8. This line normally operates at 220 volts direct current, but 220 volts, or 440 volts single-phase alternating current, can be switched onto it if desired. There is no connection between the line through the bore hole and the instrument circuits.

INSTRUMENTS USED IN TESTS

The instruments used in 1918 were described in great detail in Bulletin 167, beginning on page 38. Changes during the present series of tests were limited. The chronograph and its auxiliaries were unchanged. In some tests it was desirable to obtain more records than there were pens on the chronograph, making it necessary

[14] An old chain-breast machine is the only one at present available.

to obtain two records on a single pen. This can be done when two events can be selected whose sequence is definitely known. In addition, one must make and the other break the circuit. The first event in making its record prepares the line for the second, and interference is avoided.

The tin-foil indicators were not changed in form, but a holding pipe was designed to be placed in the rib at any point with a small amount of labor; a three-fourths-inch conduit pipe carries the wires to the nearest station, where they are connected on the terminal board to the desired chronograph circuit. In this way it was possible to place the tin foils at any point between the regular large instrument stations without going to the expense of constructing a small instrument station.

The use of air-direction indicators was continued, and a fourth one was made. A device termed "a gas-velocity recorder" was also designed by H. P. Greenwald and constructed; it is hoped that this will give some idea of the velocity of the air and the variations of velocity, as well as the direction. The instrument is nothing more than a combined air-direction indicator and manometer. The central shaft of the indicator is threaded and carries a nut, and the angular movement of the shaft causes a longitudinal movement of the nut which moves a pin and causes the mirror in the light box to tilt in the same manner that the pressure on the diaphragm of a regular manometer does. Preliminary trials have given interesting records that greatly augment those obtained with the indicating instruments.

The sliding vane or trolley, intended to determine if possible the velocity of the explosive media as distinct from the explosive combustion velocity within those moving media, was abandoned. Some results of this instrument were reported in Bulletin 167. (Table 2, p. 45.) The difficulty of interpreting the records and the lack of knowledge concerning the actual occurrences during the time of travel made it desirable to develop some other instrument, such as the modified air-direction indicator described.

Five Bureau of Mines manometers and three French-type manometers were available for pressure measurements. The design was not changed from that described on pages 49 to 51 of Bulletin 167.

Five model C automatic samplers were available for use. A group of four was used at E 950 (fig. 3) for obtaining products of explosions. In most tests these were operated automatically by the flame burning the tin foil in the magnetic control circuit, at E 1050. However, in a number of tests the samples were taken at longer intervals by breaking the control circuit at the observatory to obtain the composition of the atmosphere 15 seconds to 5 minutes after the explosions. A station for one sampler was constructed at E 1280 in the ignition zone, and in tests using gas in the air current this sampler was operated from the observatory about 1 second before firing the shot, in order to obtain an exact sample of the gas present.

The photograph-paper recorder was the standard for determining the length of flame in the present tests. The use of tufts of guncotton was abandoned, and the matches were restricted in number and used only as a means of rapidly determining the approximate flame length on entering the mine after an explosion.

No progress was made in measuring the temperature of explosions. The use of metal foil of different melting temperatures reported in Bulletin 167 was not satisfactory, and the results would probably be indicative only of continued combustion. It is evident that a photographic method will be the only one rapid enough to make determinations of any value. A method using color filters and panchromatic film is projected, but has not been fully developed.

Beyond a few minor changes made necessary by the changes in the instruments, the manipulation during the test is the same as described on page 55 of Bulletin 167. Also, the methods of measuring and plotting the data are unchanged.

GAS SAMPLES COLLECTED WITH AUTOMATIC SAMPLERS

The method of sampling and analysis and the results obtained before 1918 were discussed in considerable detail in Bulletin 167, pages 109 to 131. Both the model A and the model C samplers were used for a short time after 1918 in order to find the composition of samples taken simultaneously at the rib and at a distance from the rib. After enough information was collected use of the model A sampler was discontinued. A total of 231 samples was collected from 1918 to 1924. All of these were not of value, but the results of the more important are given in Table 1.

TABLE 1.—*Results of analyses of gases collected in automatic samplers at station E 960 during explosion tests*

PART A.—SAMPLES COLLECTED SIMULTANEOUSLY NEAR THE RIB AND ABOUT 27 INCHES FROM IT

Test No.	Kind of test	Data on the tests: Kind of coal[2]	Size of coal[3]	Ratio of coal to shale dust	Gas used, per cent	Flame velocity at E 950, feet per second	Location of point of sampling[4]	Time of sample[1]: Based on fusing of E 950 tin foil	Based on start of E 950 flame photograph	Based on end of E 950 flame photograph	Pressure at E 950 at time of sampling, pounds per square inch	Analysis, per cent: CO_2	O_2	CO	$CH_4 + C_2H_6$	N_2	H_2	Time between samples, second
501	Ignition	A	20–20	(5)	0.0	350	Midway	0.00	+0.31	−0.11	+3.7	10.7	7.4	0.3	0.3	80.6	0.2	0.03
							Rib	+.03	+.34	−.08	+3.5	5.7	13.9	.3	.1	79.9	.0	
501	do	A	20–20	(5)	.0	350	Midway	+.98	+1.29	+.87	.0	13.6	2.9	3.3	1.1	76.6	2.0	.03
							Rib	+.95	+1.26	+.84	.0	12.3	5.3	.0	.5	81.8	.0	
525	do	B	20–20	80:20	.0	750	Midway	+1.13	+1.23	+.53	−1.1	14.2	6.7	1.5	.8	76.2	.6	.02
							Rib	+1.11	+1.21	+.51	−1.1	.3	20.6	.1	.0	79.0	.0	
526	Propagation	B	20–20	50:50	.0	100	Midway		+1.08	+.34	.0	13.5	5.1	.3	.1	81.0	.0	.04
							Rib		+1.12	+.38	.0	4.6	14.6	.8	.0	81.0	.0	
534	Ignition	B	20–20	50:50	2.1	750	Midway	+.11	+.85	−.05	+21.4	5.4	12.9	3.0	.6	78.1	.0	.03
							Rib	+.14	+.88	−.02	+19.5	1.2	18.5	.8	.2	79.3	.0	
549	Propagation	C	20–40	40:60	.0	450	Midway	−.10	−.06	−.22	+7.2	11.0	7.5	.8	.3	80.4	.0	.13
							Rib	+.03	+.07	−.09	+8.1	.8	20.1	.0	.0	79.2	.0	
549	do	C	20–40	40:60	.0	450	Midway	+.23	+.27	+.11	+4.8	8.3	10.8	.7	.4	79.6	.2	.08
							Rib	+.31	+.35	+.19	+2.8	3.7	16.9	1.9	.0	77.5	.0	
555	Ignition	C	20–40	30:70	2.1	75	Midway	+5.25	+5.68	+4.81	−.2	5.0	14.1	.3	.5	80.0	.1	.03
							Rib	+5.22	+5.65	+4.78	−.2	2.3	17.6	.3	.7	79.1	.0	
556	do	C	20–40	60:40	.0	1,000	Midway	+.20	+.28	+.15	+6.2	12.8	.5	8.7	.7	72.1	4.9	.01
							Rib	+.21	+.29	+.16	+5.7	6.3	13.9	.1	.1	79.3	.3	
556	do	C	20–40	60:40	.0	1,000	Midway	+1.18	+1.26	+1.13	−1.2	6.3	12.0	2.5	.7	77.8	.7	.05
							Rib	+1.13	+1.21	+1.08	−1.2	1.9	18.5	.6	.1	78.8	.1	
558	Propagation	B	(6)	30:70	.0	200	Midway	−.33			+6.6	10.1	8.8	1.1	.0	80.0	.0	.04
							Rib	−.37			+6.2	.2	20.6	.2	.0	79.0	.0	
558	do	B	(6)	30:70	.0	200	Midway	+.01			+.7	7.0	12.9	.8	.0	79.3	.0	.10
							Rib	−.09			+3.5	1.5	18.9	.3	.0	79.3	.0	
560	Ignition	B	20–20	80:20	.0	500	Midway	−.16	+.01	−.16	+9.5	2.1	18.2	.5	.0	79.2	.0	.08
							Rib	−.08	+.09	−.08	+9.9	.3	20.5	.0	.0	79.2	.0	

PART B.—SAMPLES SHOWING CHANGES OF GAS COMPOSITION WITH PASSAGE OF FLAME

Test No.	Kind of test	Data on the tests: Kind of coal [2]	Size of coal [3]	Ratio of coal to shale dust	Gas used, per cent	Flame velocity at E 950, feet per second	Number of sample	Time of sample [1]: Based on fusing of E 950 tin foil	Based on start of E 950 flame photograph	Based on end of E 950 flame photograph	Pressure at E 950 at time of sampling, pounds per square inch	Analysis, per cent: CO_2	O_2	CO	$CH_4+C_2H_6$	N_2	H_2
502	Propagation	A	20-20	40:60	1.2	75	1	−0.86	+0.23	−0.66	+2.0	5.86	13.27	0.28	0.34	80.25	0.00
							2	−.37	+.72	−.17	−.3	8.98	10.10	.02	.05	80.85	.00
							3	+.11	+1.20	+.31	−1.0	11.09	7.13	.44	.12	81.22	.00
515	do	D	20-20	50:50	.0	125	1	−.33	----	----	+1.4	4.7	15.0	.3	.0	80.0	.0
							2	+.21	----	----	−.9	3.0	17.2	.5	.0	79.3	.0
							3	+.75	----	----	−.5	12.6	6.7	.1	.0	80.6	.0
							4	+1.28	----	----	−.9	7.0	12.0	.1	.0	80.9	.0
526	do	B	20-20	50:50	.0	100	1	----	+.13	−.61	+3.8	11.6	6.5	1.0	.0	80.9	.0
							2	----	+.61	−.13	+1.0	7.3	12.6	.3	.0	79.8	.0
							3	----	+1.08	+.34	+.2	13.5	5.1	.3	.1	81.0	.0
							4	----	+1.55	+.81	+.4	9.5	9.6	1.1	.0	79.6	.2
531	do	B	20-20	40:60	1.2	350	1	−.11	+.05	−.25	+1.9	12.5	4.7	1.7	1.0	80.1	.0
							2	+.22	+.38	+.08	−.4	10.4	8.2	.8	.2	80.4	.0
							3	+.54	+.70	+.40	+.4	14.0	4.2	.0	.8	81.0	.0
544	do	B	20-20	40:60	.9	300	1	−.22	−.02	−1.21	+4.0	3.8	16.4	.8	.0	78.9	.1
							2	+.09	+.29	−.90	+3.1	9.2	8.5	1.1	.4	80.8	.0
							3	+.42	+.62	−.57	+.8	12.2	5.1	2.3	.0	79.6	.8
							4	+.73	+.93	−.26	−.8	7.6	10.9	1.0	.4	79.9	.2
549	do	C	20-40	40:60	.0	450	1	−.10	−.06	−.22	+7.2	11.0	7.5	.8	.3	80.4	.0
							2	+.23	+.27	+.11	+4.8	8.3	10.8	.7	.4	79.6	.2
							4	+.84	+.88	+.72	−2.2	10.9	7.9	1.1	.2	79.6	.3
552	do	C	20-40	25:75	1.4	75	1	−.81	−.18	−.81	+3.3	.4	20.2	.1	1.4	77.9	.0
							2	−.49	−.14	−.49	+.5	3.1	17.1	.4	.8	78.3	.3
							4	+.14	+.77	+.14	−.4	10.0	8.8	.1	.1	81.0	.0
558	do	B	20-20	30:70	.0	200	1	−.33	----	----	+6.2	10.1	8.8	1.1	.0	80.0	.0
							2	−.01	----	----	+3.5	7.0	12.9	.8	.0	79.3	.0
567	do	B	20-20	40:60	.8	50	1	−1.40	----	----	+.8	.1	20.6	.0	.6	78.7	.0
							2	−1.11	----	----	−.7	1.9	18.6	.6	.3	78.3	.3
							3	−.82	----	----	−1.0	3.6	16.3	.3	.0	79.8	.0
585	do	E	20-20	50:50	.0	50	1	−1.42	----	----	+1.6	1.0	20.6	.0	.0	78.4	.0
							2	−1.12	----	----	−.8	.3	20.6	.0	.0	79.1	.0
							3	−.79	----	----	−.7	.5	20.4	.0	.0	79.1	.0
587	do	E	(6)	40:60	.0	600	1	−.14	----	----	+6.7	14.9	2.1	2.3	.5	80.2	.0
							2	+.15	----	----	+4.0	15.3	1.9	.2	.3	82.1	[7] .0
							3	+.45	----	----	−1.0	12.9	5.3	.0	.2	81.6	.0
							4	+.76	----	----	−1.2	6.9	12.5	.2	.2	80.2	.0
631	do	F	(6)	30:70	.0	125	1	−.67	----	----	.0	.65	20.21	.03	.04	79.07	.00
							2	−.32	----	----	.0	.05	20.91	.00	.00	79.04	.00
							4	+.37	----	----	−2.0	12.52	6.04	.64	.14	80.60	.04

See notes on page 20.

TABLE 1.—*Results of analyses of gases collected in automatic samplers at station E 960 during explosion tests*—Continued

PART C.—SAMPLES SHOWING CHANGES IN GAS COMPOSITION IMMEDIATELY AFTER PASSAGE OF FLAME

Test No.	Kind of test	Data on the tests: Kind of coal [2]	Data on the tests: Size of coal [3]	Data on the tests: Ratio of coal to shale dust	Data on the tests: Gas used, per cent	Flame velocity at E 950, feet per second	Number of sample	Time of sample [1]: Based on fusing of E 950 tin foil	Time of sample [1]: Based on start of E 950 flame photograph	Time of sample [1]: Based on end of E 950 flame photograph	Pressure at E 950 at time of sampling, pounds per square inch	Analysis, per cent: CO_2	O_2	CO	$CH_4 + C_2H_6$	N_2	H_2	Remarks
501	Ignition	A	20-20	All coal.	0.0	350	1	0.00	+0.31	−0.11	+3.7	10.7	7.4	0.3	0.3	80.6	0.2	C_2H_4, 0.5.
							2	+.49	+.80	+.38	.0	15.2	1.7	1.7	.4	79.9	1.0	C_2H_4, 0.1.
							3	+.98	+1.29	+.87	.0	13.6	2.9	3.3	1.1	76.6	2.0	C_2H_4, 0.5.
509	Propagation	G	20-20	40:60	2.0	600	1	+.25	+.30	+.15	+2.4	11.9	4.5	1.4	.9	81.2	.1	
							2	+.70	+.75	+.60	−.6	10.2	7.7	.2	.3	81.6	.0	
520	Ignition	D	20-20	70:30	.0	800	1	+.14	+.28	−.51	+3.4	11.9	5.9	.4	.0	81.8	.0	
							2	+.62	+.76	−.03	−.5	6.2	12.6	.5	.0	80.7	.0	
							3	+1.09	+1.23	+.44	−1.0	4.6	14.8	.5	.0	80.1	.0	
							4	+1.56	+1.70	+.91	−.8	4.5	14.2	1.2	.1	79.8	.1	
521	do	B	20-20	80:20	.0	750	1	+.12	+.25	−.03	+13.7	13.6	1.0	5.0	1.1	77.7	1.6	
							2	+.62	+.75	+.47	----	8.2	8.6	3.2	.5	77.8	1.7	
							3	+1.11	+1.24	+.96	----	6.0	11.9	2.3	.3	78.1	1.4	
525	do	B	20-20	80:20	.0	750	1	+.10	+.20	−.50	+7.2	12.4	1.3	5.9	.6	75.0	4.2	C_2H_4, 0.6.
							2	+.64	+.74	+.04	−1.8	6.8	11.3	1.7	.0	78.6	.8	C_2H_4, 0.8.
							3	+1.13	+1.23	+.53	−1.1	14.2	6.7	1.5	.8	76.2	.6	
							4	+1.63	+1.73	+1.03	−.4	9.0	8.8	1.4	.2	79.9	.7	
545	Propagation	B	20-20	50:50	.0	125	1	+.16	+.46	+.04	−.1	.5	20.4	.0	.0	79.1	.0	
							2	+.50	+.80	+.38	−.3	5.4	14.6	.5	.0	79.5	.0	
							3	+.80	+1.10	+.68	−.2	8.5	11.5	.0	.1	79.9	.0	
546	Ignition	C	20-40	80:20	.0	2,100	1	+.18	+.26	+.10	+15.0	10.0	4.5	8.2	2.2	72.0	3.1	
							2	+.48	+.56	+.40	+6.5	12.0	.6	10.2	2.2	70.2	4.8	
							3	+.81	+.89	+.73	+1.8	11.5	1.3	10.4	1.5	70.3	5.0	
							4	+1.16	+1.24	+1.08	----	10.2	4.1	8.0	1.2	72.6	3.9	
555	do	C	20-40	30:70	2.1	100	1	+4.94	+5.37	+4.50	−.3	6.5	12.3	.1	.3	80.7	.1	
							2	+5.25	+5.68	+4.81	−.2	5.0	14.1	.3	.5	80.0	.1	
							3	+5.57	+6.00	+5.13	.0	2.7	17.1	.3	.4	79.3	.2	
							4	+5.92	+6.35	+5.48	----	.7	19.7	.4	1.1	78.0	.1	
556	do	C	20-40	60:40	.0	1,000	1	+.20	+.28	+.15	+6.2	12.8	.5	8.7	.7	72.1	4.9	C_2H_4, .03.
							2	+.53	+.61	+.48	−.6	8.5	9.2	2.9	.5	77.6	1.3	
							3	+.86	+.94	+.81	−1.6	8.2	9.5	3.2	.8	77.5	.8	
							4	+1.18	+1.26	+1.13	−1.1	6.3	12.0	2.5	.7	77.8	.7	
572	do	B	(6)	40:60	1.2	1,000	1	+.25	----	----	+2.5	10.0	8.1	1.5	.4	80.0	.0	
							2	+.57	----	----	−1.0	8.4	9.2	2.5	.7	78.5	.7	
							3	+.88	----	----	−2.3	.1	20.6	.0	.7	78.6	.0	
							4	+1.19	----	----	−1.8	.1	20.5	.0	1.1	78.3	.0	

582	......do..................	E	20–20	80:20	.0	500	1	+.35	+.48	+.24	+.9	13.3	4.9	.0	.1	81.7	.0
							2	+.65	+.78	+.54	−1.9	8.6	9.7	.0	.2	81.5	.0
							4	+1.25	+1.38	+1.14	−1.6	9.2	9.4	.0	.0	81.4	.0
584	......do..................	E	20–20	70:30	1.1	1,200	1	+.24	+.32	+.12	+7.2	11.1	5.1	1.6	.8	80.9	.5
							2	+.54	+.62	+.42	+.7	6.8	10.0	.4	1.0	81.8	.0
							3	+.84	+.92	+.72	−2.1	10.5	5.3	2.1	.6	80.6	.9
							4	+1.14	+1.22	+1.02	−1.2	11.9	4.9	.0	.6	82.4	.2

See notes on page 20.

TABLE 1.—*Results of analyses of gases collected in automatic samplers at station E 960 during explosion tests*—Continued

PART D.—SAMPLES SHOWING COMPOSITION AT E-950 AFTER EQUILIBRIUM HAS BEEN ESTABLISHED [8]

Test No.	Kind of test	Data on the tests				Flame velocity at E-950, feet per second	Number of sample	Time of sample based on time of ignition[8]	Analysis, per cent					
		Kind of coal[2]	Size of coal[3]	Ratio of coal to shale dust	Gas used, per cent				CO_2	O_2	CO	$CH_4 + C_2H_6$	N_2	H_2
633	Propagation	F	([6])	25:75	1.1	600	1	+5	8.66	9.46	1.14	0.56	80.11	0.07
							2	+65	.68	19.86	.19	.79	78.48	.00
							3	+185	4.82	14.17	1.23	.98	78.56	.24
634	do	F	([6])	20:80	1.5	([9])	1	+5	.05	20.63	.21	1.30	77.81	.00
							2	+185	.27	20.35	.25	1.17	77.96	.00
636	do	H	20-20	40:60	.0	([10])[7]	2	+60	.06	20.89	.00	.00	79.05	.00
							3	+180	2.44	17.46	.65	.23	79.02	.20
							4	+240	3.15	16.34	.96	.39	78.88	.28
637	do	I	20-20	50:50	.0	([11])	1	+60	.05	20.70	.20	.00	79.05	.00
							2	+180	1.15	19.36	.25	.02	79.12	.10
							3	+240	4.21	15.33	.99	.23	78.81	.43
639	Ignition	I	20-20	60:40	1.8	700	2	+20	.85	19.48	.35	1.22	78.10	.00
							3	+60	.48	20.03	.31	1.34	77.84	.00
							4	+180	.2	19.9	.4	1.3	78.1	.1
640	Propagation	I	20-20	30:70	1.9	75	1	+5	11.68	5.45	1.12	1.02	80.73	.00
							2	+20	2.46	17.44	.22	1.05	78.83	.00
							3	+65	4.51	14.89	.27	.94	79.39	.00
							4	+150	.25	20.38	.31	1.38	77.68	.00

[1] Time in parts A, B, and C of this table is taken in seconds with reference to either the fusing of the tin foil at E 950, the time of the start of the flame photograph record on the E 950 manometer film, or the end of this flame photograph record. If the sample is taken prior to the base to which it referred, the time is negative; if after the base, the time is positive.

[2] Explanation of symbols:
- A. Pinnacle or Argo bed, Routt County, Colo
- B. No. 5 bed, Saline County, Ill.
- C. No 5 bed, McKinley County, N. Mex.
- D. Pittsburgh bed, experimental mine
- E. Nickel Plate bed, Jefferson County, Ala.
- F. Silkstone bed, Yorkshire, England.
- G. Wadge bed, Routt County, Colo.
- H. Raton bed, Colfax County, N. Mex.
- I. No. 1 bed, Sweetwater County, Wyo.

[3] Explanation of symbols:
- 20–20. 20-mesh dust of which 20 per cent would pass 200-mesh.
- 20–40. 20-mesh dust of which 40 per cent would pass 200-mesh.

[4] The samples taken at the point near the rib have been designated rib. Those taken 27 inches from the rib have been designated midway, as this point is approximately midway between the rib and the center of the entry.

[5] All coal.

[6] Pulverized.

[7] C_2H_4, 0.2 per cent.

[8] The time given for the samples in part D of this table is measured in seconds from the firing of the blown-out shot from the cannon.

[9] Flame to E 1125 only.

[10] Flame to E 1100 only.

[11] Flame to E 1025 only.

COMPARISON OF SAMPLES COLLECTED AT RIB AND 27 INCHES FROM RIB

Table 1 is divided into four parts. Part A gives the analyses of 13 pairs of samples collected at virtually the same moment in the model A sampler at the rib and in the model C sampler 27 inches from the rib. These two points are designated "Rib" and "Midway," respectively, in the table. The latter point is about midway between the rib and the center of the entry. The time each sampler is open for the inrush of gas is 0.05 second, and the time interval between the start of operation of the two samplers was 0.05 second or less in 9 of the 13 tests. In the other 4 tests the interval varied from 0.08 to 0.13 second. Interpretation of the analyses of the samples is greatly aided by the flame photograph recorded by the Bureau of Mines manometer at instrument station E 950.

TEST 501

Two pairs of samples were collected in test 501, the first pair in the middle of the passage of the flame and the second pair about 1 second later. The first pair was collected when the E 950 tin foil fused, which was 0.3 second after the flame was first photographed on the manometer. The sample taken 27 inches from the rib showed 10.7 per cent carbon dioxide, whereas at the rib there was only 5.7 per cent. The oxygen content was 7.4 per cent and 13.9 per cent in the respective samples. Thus 0.3 second after the flame appeared, combustion was not complete 27 inches from the rib and was very weak at the rib.

The second pair of samples was taken 0.85 second after the flame passed. There was still 5.3 per cent free oxygen at the rib as compared with 2.9 per cent 27 inches from the rib, but more significant than this is the fact that there was 3.3 per cent carbon monoxide, 1.1 per cent methane, and 2 per cent hydrogen in the outer sample, whereas at the rib there was no carbon monoxide or hydrogen and only 0.5 per cent methane. It must be concluded that burning spread to the sides of the entry but was weaker at the rib. An excess of coal dust was probably carried along the walls, and both this dust and the walls would absorb some heat, making the temperature lower than at points away from the ribs. Eddying current could not have played a very important part in the formation of the sample near the rib, otherwise some of the carbon monoxide and hydrogen would have been carried into the sample from the center.

TEST 525

In test 525 two samples were collected 0.5 second after the flame passed; the sample at the rib was practically normal air, whereas the outer sample showed 14.2 per cent carbon dioxide, 1.5 per cent

103804°—27——3

carbon monoxide, 0.8 per cent methane, and 0.6 per cent hydrogen. This remarkable difference may possibly be due to a leak in the model A sampler admitting air to the bottle before the explosion. An alternate possibility is that the flame did not reach the side, the radiant heat from the central combustion zone sufficing to melt the tin foil of the circuit breaker but not to sustain combustion. It might also be assumed that the rib sample was from a pocket of fresh air trapped in a hole along the rib during the explosion but, if so, it is an isolated occurrence.

TEST 526

In test 526 the samples were taken 0.35 second after the flame passed. Here again combustion was radically different in the two samples, as there was 14.6 per cent oxygen at the rib and only 5.1 per cent 27 inches from the rib.

TEST 534

In test 534 the samples were taken coincident with the end of the flame-photograph record on the manometer and about 0.9 second after the first appearance of flame. More of the oxygen had combined in the midway sample than in the rib sample, but the former still had 12.9 per cent oxygen present, which seems remarkable, as this sample was taken at the rear of the flame of a strong and moderately rapid explosion. The sample contained 3 per cent of carbon monoxide and 0.6 per cent combustible hydrocarbons. The composition was such that it is necessary to consider the possibility of air having leaked into the bottle before the explosion.

TEST 549

In test 549 two pairs of samples were collected. In the first pair the model C sampler was operated 0.06 second before the start of the flame photograph on the manometer and showed 11 per cent carbon dioxide, 0.8 per cent carbon monoxide, and 0.3 per cent methane. This by itself is a remarkable result. However, if allowance is made for possible errors in time measurements and failure to record the start of the flame because of interference of dust cloud, it may be possible that this sample was taken near the tip of the flame, which (as shown by tests reported in Bulletin 167, p. 41) advances in a point or wedge shape, centrally. Compared with this is the sample taken at the rib 0.13 second later, which showed normal air with a slight trace (0.8 CO_2) of products of combustion. The second pair of samples in test 549 was taken about 0.15 second after the flame had passed. Combustion was much more complete near the center of the entry.

TEST 555

In test 555 two samples were collected 4.8 seconds after the flame had passed. This was a weak, slow explosion in a mixture near the limit of explosibility, although there was 2.1 per cent natural gas present. The tin foil at E 1050 on which operation of the samplers depended did not fuse when the flame passed, but was ruptured later by the gas movements. It might be expected that in nearly 5 seconds after the flame had passed, the composition of the gases would have been made more uniform when mixed by eddy currents, yet there was only 2.3 per cent carbon dioxide at the rib as compared with 5.0 per cent 27 inches from the rib.

TEST 556

In test 556—an explosion of high velocity but low pressure—two samples were collected 0.15 second after the flame had passed. The sample collected 27 inches from the rib contained 0.5 per cent oxygen, 12.8 per cent carbon dioxide, 8.7 per cent carbon monoxide, 0.7 per cent methane, and 4.9 per cent hydrogen. This shows a very strong and hot explosion with an excess of dust present, and reaction of this excess hot dust reduced part of the CO_2 to CO. The water-gas reaction may be responsible for part of the carbon monoxide and hydrogen. Contrast with this the sample collected at the rib where there was 13.9 per cent oxygen, 6.3 per cent carbon dioxide, and a total of 0.5 per cent carbon monoxide, methane, and hydrogen. Two more samples collected about 1 second later, after the direction of movement of the gases had been reversed and some fresh air had been drawn into the zone, showed that the relative composition at the two points was not greatly changed by dilution.

Additional samples taken in tests 558 and 560 are listed in Table 1 and give evidence confirming that which has been discussed.

CONCLUSIONS

These results show definitely that combustion in the zone of an explosion does not proceed from the central part toward the walls of a passageway with the degree of completeness that it progresses longitudinally because of the cooling influence of the walls and excess coal dust in the cloud. In weak explosions the flame may reach the walls only at irregular intervals as obstructions of various kinds cause it to change its course. From this one may argue that the fusing of the tin-foil strips is at times caused by radiant heat rather than by direct contact with the hot gases, and the first heating of the strip is certainly due to this cause. It is possible that if the tin-foil circuit breakers could be set out a short distance from the rib the record would be more uniform and the foil would fuse earlier in the flame, as recorded by the photograph on the manometer. However, the violence of the explosion would then involve mechanical difficulties which must be overcome. It is also desirable to set the four model C samplers at equal distances from the rib to the center of the entry, and take simultaneous samples to find the change of composition over the whole range from the center to the side of the entry.

SAMPLES SHOWING CHANGE OF COMPOSITION OF GASES WITH PASSAGE OF FLAME

Part B of Table 1 shows data on 12 sets of samples collected with the model C samplers at E 950. In each of these 12 tests the first sample was taken before rupture of the tin foil at E 950, and in three tests the first sample was collected before the flame started to photograph on the manometer at E 950. Before the explosion there was, of course, normal air at the point of sampling, and the purpose of taking this set of samples was to determine, if possible, (1) the time when change from normal composition starts and (2) its relation to the approach and passage of the flame. As previously indicated, the time of rupture of the tin foil is not a satisfactory basis for determining the relation of the time of collecting gas samples to their composition. The best basis is the flame photograph recorded by the manometers. The tin foil has a lag of fusion that varies with the violence of an explosion. In a violent explosion the foil will be ruptured very soon after the flame appears. With a very weak explosion it may not be ruptured till the flame has passed. All of the tests listed in part B of Table 1 are weak, slow explosions, and it happens that they are all propagation tests. This is more than mere coincidence, because operation of the samplers was always started by the fusion of the foil at E 1050 and it is only with slow explosions that a longer time is required for the flame to travel from E 1050 to E 950 than to complete the sequence of operations leading to the taking of the first sample. In an ignition test the flame either is extinguished fairly close to the origin, or an explosion is caused that develops high pressure and relatively strong velocity in the last 100 feet of its travel to the end of the test zone. The propagation test with a mixture near the explosive limit is the only kind that will give explosions having a low flame velocity from E 1050 to E 950.

SAMPLES COLLECTED AHEAD OF FLAME

In part B of Table 1 are listed the analyses of seven samples that showed either normal air or air with a very small content of products of combustion. In test 552 the first sample was taken 0.18 second before the flame began to photograph on the manometer at E 950. The sample showed normal air except for 0.1 per cent carbon monoxide, 0.4 per cent CO_2, and 1.4 per cent methane. The methane had been introduced into the air current before the shot was fired, as the test record shows. This sample was analyzed on an Orsat apparatus, and it is doubtful whether there was any CO or appreciable amount of CO_2 present, as the amounts shown are within the limit of error of this type of analysis. From the estimated velocity of the flame and from the time that the sample preceded the flame record at E 950 it is judged that the sample was taken about 15 feet ahead of the flame, and if there was any distillation caused by radiant heat it did not show in the gas analysis.

In test 567 the first sample showed normal air with methane that had been added before the shot. This sample was taken 1.4 seconds before the fusing of the foil at E 950, but unfortunately there was no flame photograph on the manometer with which comparison could be made. The three samples of test 585 were taken at 1.42, 1.12, and 0.79 second before the fusing of the foil, and all showed nearly normal air (No. 1 has 1 per cent CO_2), but again there was no flame photograph. It can be noted, however, that the last sample was taken at nearly the same time before the rupture of the tin foil, as was the first sample of test 552 discussed in the preceding paragraph. In test 631, samples were collected 0.67 and 0.32 second before the rupture of the foil at E 950; there was no flame photograph at E 950. The first sample showed some traces of combustion, but the second showed pure air. In the absence of the flame photograph it is virtually impossible to offer an explanation of this. The evidence of all these tests is that if there is any distillation of coal-dust particles ahead of the flame in weak explosions, the amount is very small or the distance ahead of the flame in which distillation takes place is very limited. However, this applies only to distillation on a measurable scale. If a film of distilled gases were formed about each coal particle, or the gases were burned as fast as produced, the samples would not show them.

Further evidence is offered by the first sample of test 544, which was taken 0.02 second before the start of the flame photograph, and shows definitely the start of combustion. When so small a time interval is measured the errors of all the measurements must be taken into consideration, as well as the time of operation of the sampler (0.05 second), and it is possible that this sample might have been collected in the tip of the flame.

The first sample of test 549 is remarkable, as it was apparently taken 0.06 second before the start of the flame photograph and shows an advanced stage of combustion. This is the only sample giving evidence of this kind, and as a number of samples show the contrary it is thought that either there is some error in the time measurements of test 549 or that the flame was screened from the film of the manometer by a dense cloud of dust.

SAMPLES COLLECTED IN THE FLAME

Combustion is active and fairly complete in the tip of the flame, as is shown by the first samples of tests 526 and 531. Thus in test 531 the first sample was collected 0.05 second after the start of the flame photograph and showed 12.5 per cent carbon dioxide, 1.7 per cent carbon monoxide, and 4.7 per cent oxygen. The first samples of tests 558 and 587 offer confirming evidence, although this is somewhat injured by the lack of the flame-photograph record. It will be noted that, with the exception of test 526, all these were among the stronger and more rapid explosions of this group. With the weaker explosions combustion is not so advanced in the first samples, but the percentage of carbon dioxide increases from sample to sample. Examples are tests 502, 515, 552, and 567. Test 544 is also of this character, but was a faster explosion than the others cited.

One noticeable fact in all of these samples (part B, Table 1) is that all of the oxygen was not consumed, and the weaker the explosion the greater the oxygen content of the samples. Thus test 587 had the highest velocity, and the first two samples taken showed 2 per cent of free oxygen. Fresh air drawn in by a reversal of gas movement then caused the oxygen content to increase to 12.5 per cent. But in tests 502, 515, 526, 552, 558, 567, 585, and 631, in which the flame velocity was 200 feet per second or less, the minimum oxygen content was 5.1 per cent and the maximum was as high as 17 per cent in certain samples taken after the flame had appeared. It is also noticeable that the products of distillation and incomplete combustion (carbon monoxide, hydrogen, and methane) are frequently absent, and if present they are in much smaller amounts than in the more violent tests to be considered in the next section.[14a]

TEST 502

The results of these samples with high oxygen content indicate that in the weakest explosions the combustion was confined more to the center of the entry, and the sampler 27 inches from the rib was not in the zone of strongest combustion, just as the sampler at the rib was found to be out of the zone of combustion in tests of considerable violence. This is illustrated by the curves in Figure 4, showing the instrument records obtained in test 502 in the main entry during the period of sampling. The composition of each sample at the time it was taken is illustrated by a vertical oblong section, each division representing 20 per cent by analysis, in which the unshaded part represents oxygen and the shaded part represents carbon dioxide. In test 502 the methane, carbon monoxide, and hydrogen are too small to be shown separately and are combined as a small solid black area at the top of the section. In other similar

[14a] The relation between completeness of combustion and corresponding temperature and violence remains to be worked out.

charts, where enough of these gases were present to be plotted separately, the carbon monoxide is represented by solid black and the methane and hydrogen by a cross-hatched area, unless further separation is advisable, when the hydrogen is separately represented by a

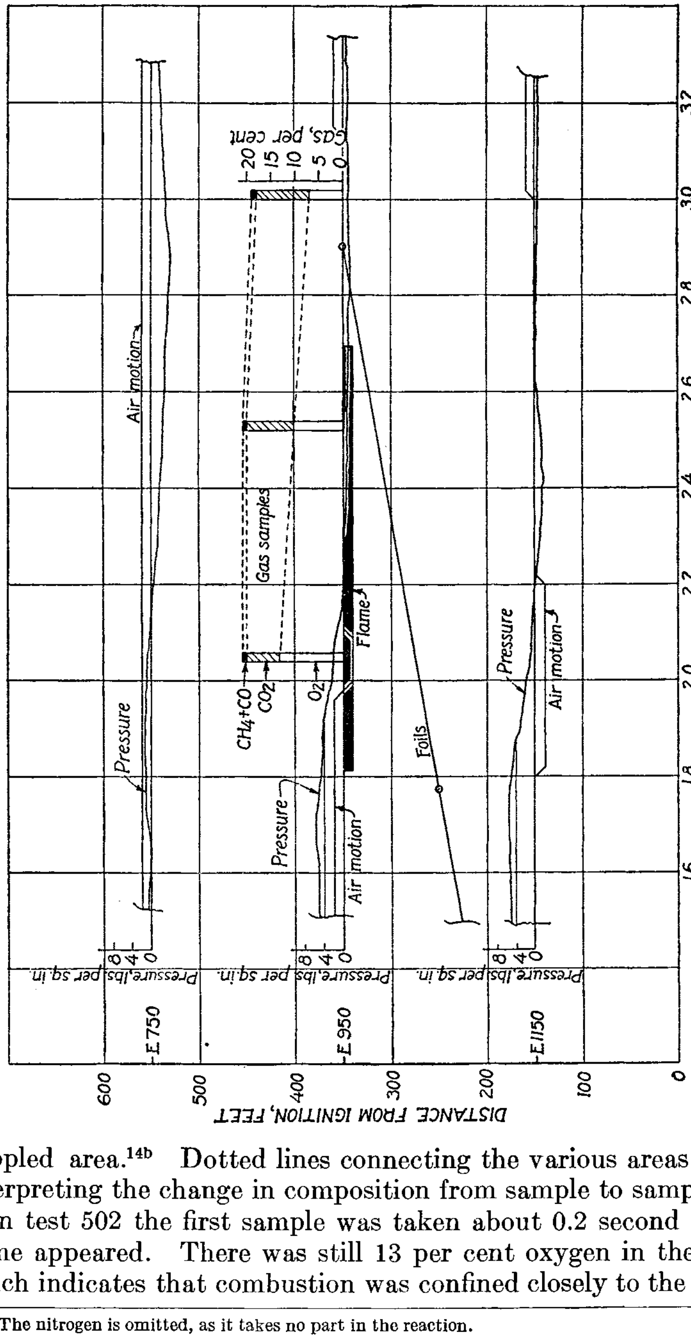

FIGURE 4.—Part of instrument records of test 502, illustrating change of composition of gases during passage of flame

stippled area.[14b] Dotted lines connecting the various areas assist in interpreting the change in composition from sample to sample.

In test 502 the first sample was taken about 0.2 second after the flame appeared. There was still 13 per cent oxygen in the sample, which indicates that combustion was confined closely to the center of

[14b] The nitrogen is omitted, as it takes no part in the reaction.

the entry and had not spread out to the sampler. The second sample was taken while the flame was still present, and the third a little more than 0.3 second after the flame had passed. The oxygen content decreased uniformly from the first to the third samples, the carbon dioxide content increased in proportion, and the total content of methane and carbon monoxide showed little change. The total content of all the gases of combustion is slightly less in the third sample than in the first two. There was no record of a reversed air movement at E 950 that would bring fresh air into the zone. The continued increase in carbon dioxide after the flame was extinguished may be due to gas being carried by eddy currents from the central zone of more complete combustion, or else there may be continued oxidation of the residual hot dust. It is noticeable that according to the records the maximum pressure at E 950 occurred before the recorded arrival of the flame, and while the flame was present the pressure decreased steadily, dropping below atmospheric pressure for the last half of the flame record. The tin foil at E 950 was not ruptured until 0.2 second after the flame photograph was ended, which gives additional evidence of the confinement of the explosion to the center of the entry.

TEST 552

Conditions of this same character are illustrated in test 552; part of the record of this test is given in Figure 5. The first sample in this test was taken before the flame arrived and was normal air, plus 1.4 per cent gas which was introduced in the air before the shot was fired and shows in the analysis. The composition of the atmosphere changed with the arrival of the flame, as shown by the second sample taken in the flame and by the third sample taken after the end of the flame-photograph record. Although the dotted lines connecting samples 1 and 2 have been drawn as though there was a uniform change of composition during the interval, this is probably in error, but the actual change can not be definitely predicted in the absence of intermediate samples. However, if one assumes that before sample 2 was taken the oxygen content of the air had decreased at the rate of decrease shown between samples 2 and 3, the presence of normal air 0.05 second before the start of the flame photograph would be required. The assumption is also that oxidation proceeded at a uniform rate in the interval from the end of the flame photograph to the taking of the third sample. The methane in the air was burned and was reduced to 0.1 per cent in the last sample, which also contained 0.1 per cent carbon monoxide and no hydrogen.

CONCLUSIONS

These results show that in weak explosions the zone of combustion is confined well to the center of the entry, and at times may not extend as far as a point midway between the center and the rib of the

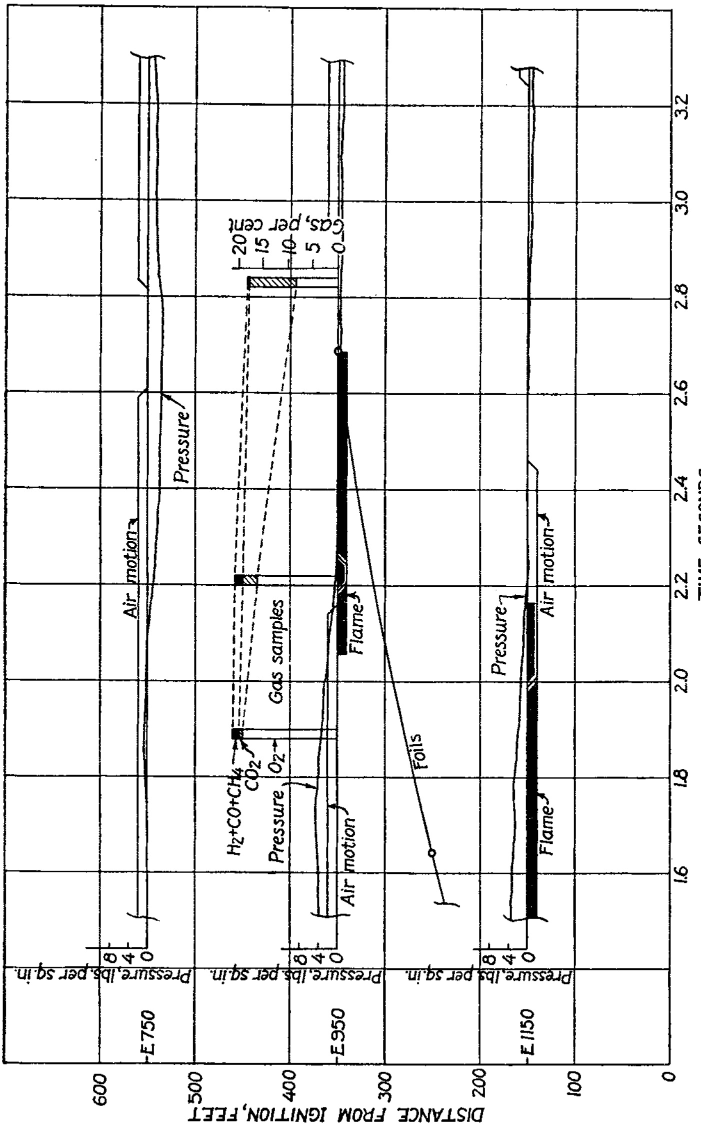

FIGURE 5.—Part of instrument records of test 552, illustrating change of composition of gases during passage of flame

entry. If there is prior distillation of coal dust by radiant heat in advance of the flame, this effect is confined to a very short or thin cross-sectional area in front of the flame and, although such conjectured predistillation may be important in the mechanism of explosive combustion, it is not of sufficient magnitude to be detected by the methods of sampling and analysis used in these tests. Conditions may be different in a rapid and violent explosion. It is important to take additional samples of the cross section at points nearer the center of the entry to determine further the composition of the gases in the first part of the flame. After the flame has passed in weak explosions, the gases contain much uncombined oxygen at points as much as 2 feet from the rib, and only small quantities of methane, hydrogen, and carbon monoxide which, if present, would be derived from distillation or from combustion with a deficiency of oxygen. Evidently there is a field of research here that has scarcely been touched.

SAMPLES SHOWING CHANGE OF COMPOSITION OF GASES AFTER FLAME HAS PASSED

Part C of Table 1 contains 12 tests in which the first sample was collected during or after the flame. In 7 of the 12 tests the first sample was collected after the flame photograph ended. These explosions are all fairly strong and rapid, as the flame had to have considerable velocity to travel from E 1050 to E 950 before the first sampler was operated. The general conclusion to be drawn from the analyses is that immediately following the flame in strong explosions the oxygen of the air is nearly all consumed and important percentages of carbon monoxide, methane, hydrogen, and frequently ethylene will be found. These gases come from the distillation and partial combustion of the excess dust suspended in the air in the presence of the hot flame. The flame extended much closer to the walls of the entry than the flame of the weaker explosions. Complete combustion was obtained with fair regularity at the point where the model C sampler was placed, 27 inches from the rib. Examples are the first sample of tests 521, 525, 556, and the second sample of tests 501 and 546, in which the oxygen content was less than 2 per cent. In four of these five samples the carbon monoxide content ranged from 5 to 10 per cent, and in the fifth it was 1.7 per cent. In three samples the high carbon monoxide was accompanied by 3 to 5 per cent of hydrogen, which may indicate that the water-gas reaction was at least partly responsible for the production of the carbon monoxide and hydrogen.

TEST 521

The samples taken a short time after the flame was extinguished showed the return of fresh air. The reason for this is that the samples are taken at the end of the explosion zone, and as soon as the flame is extinguished the cooling and contraction of gases in the test zone causes an inrush of air from points not reached by the explosion.

The change of composition can be properly interpreted only when the movement of the gases is known and the matter is best analyzed graphically. Figure 6 shows part of the instrument records and the composition of the gas samples obtained in the main entry in test 521,

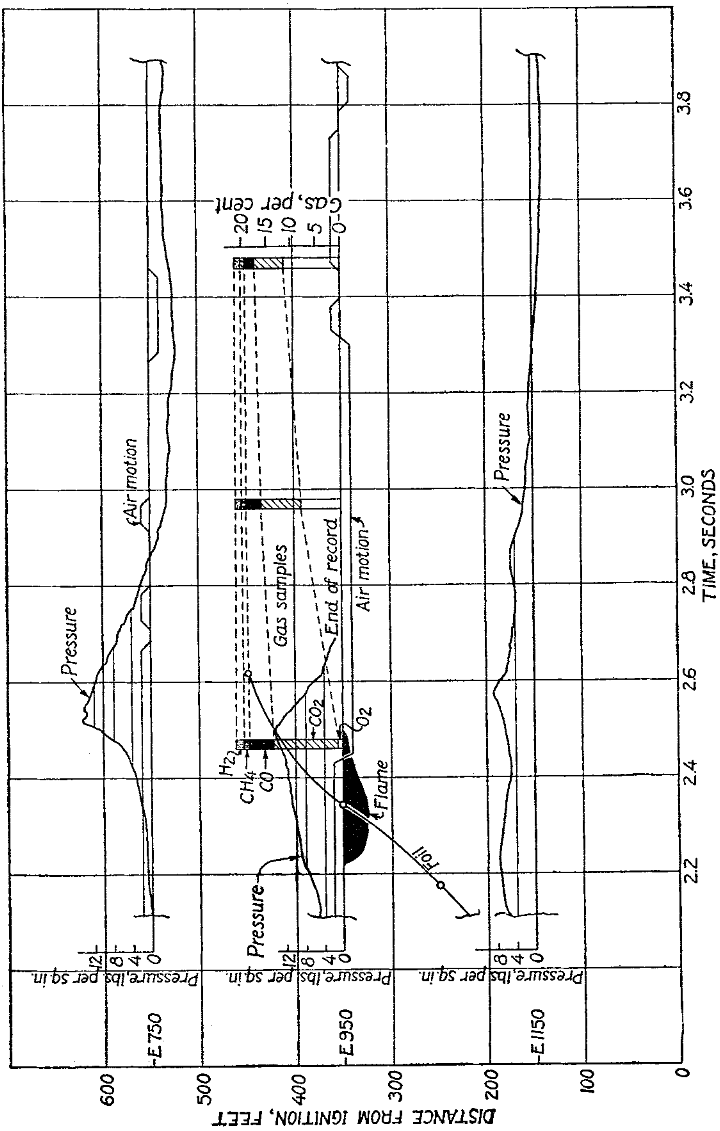

FIGURE 6.—Part of instrument records of test 551, illustrating change of composition of gases after passage of flame

and is prepared like Figures 4 and 5. The first sample at E 950 was taken just before the flame was extinguished and showed complete combustion with the presence of carbon monoxide and hydrogen. Between samples 1 and 2 the air was moving in past the samplers. The barrier did not extinguish the flame but reduced the velocity and violence of the explosion, and the gases coming back past the samplers must have been a mixture of air and products of combustion. The increased oxygen content in sample 2 indicates that combustion was weak in the zone occupied by the barrier. The

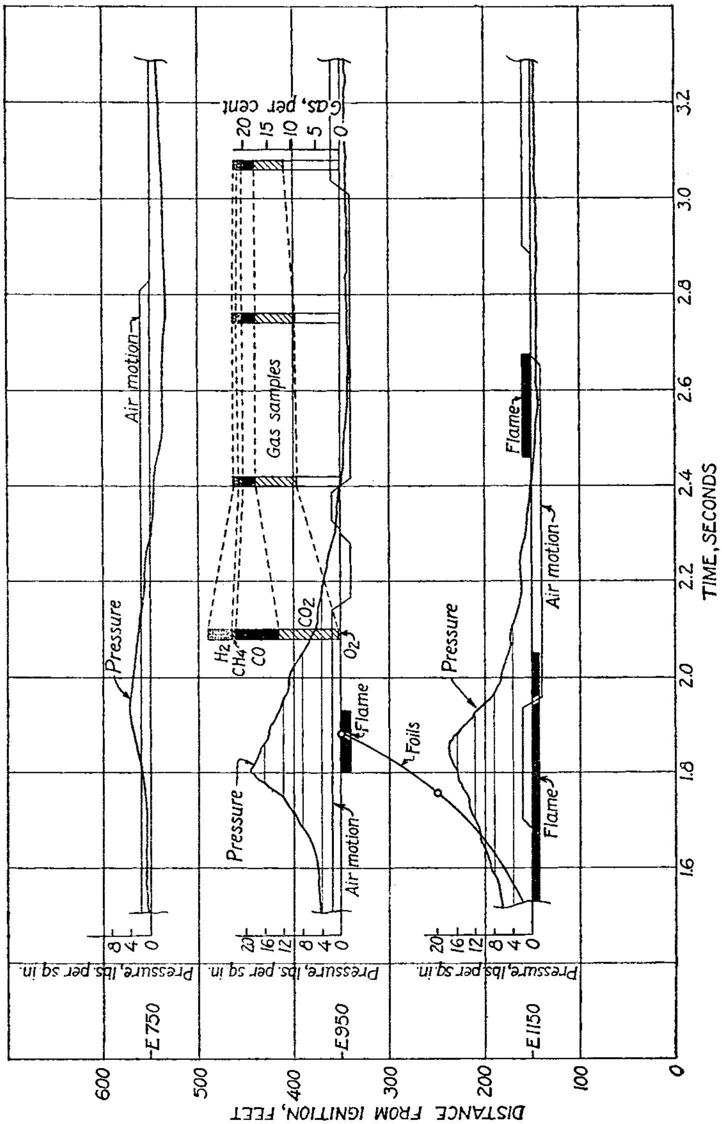

FIGURE 7.—Part of instrument records of test 556, illustrating change of composition of gases after passage of flame

gases continued to move inward for about 0.3 second after sample 2 was taken, then reversed and moved outward for 0.2 second before sample 3 was taken. As the record of the outward movement is not continuous, it was at lower velocity than the inward movement. Evidently the gases taken in sample 3 had moved in past the point of sampling and were caught on the return outby movement. The third sample shows more oxygen than the second, so a continued admixture of unburned air must be inferred.

TEST 556

Conditions of much the same character are shown in Figure 7, which is part of the record of test 556. Here again the gases contained no oxygen after the flame passed. The flame was extinguished by the barrier and unburned air was present a short distance outby the sampler. The second sample was taken after there had been an inrush lasting 0.11 second and an outrush lasting 0.06 second, so that the gas sampled must have been largely air that entered in the first inrush; there was nearly 10 per cent of oxygen in this sample. Coincident with the taking of sample 2 a second inrush started, and sample 3 was taken about the middle of it. The composition of sample 3 is approximately the same as sample 2, although it might be expected that the continued inward movement would have carried in additional fresh air. This did occur to some extent later, as is shown by the increased oxygen content of sample 4, which was taken just after the inward movement had been again reversed.

CONCLUSIONS

Equally interesting results can be observed in the plotted records of a number of other tests, which can not be given here because of lack of space. The general conclusion is that the products of combustion near the end of the zone traversed by an explosion will be rapidly diluted by the admixture of unburned air drawn in by the contraction of the cooling gases in the zone of the explosion. However, this deduction is made from samples taken near the end of a short explosion zone. In an extensive mine explosion the dilution of the gases would be much slower. Additional information can be gained, within the limits imposed by the size of the experimental mine, by using samplers at other inby points or by extending the explosion zone in the main entry some distance beyond the present point of sampling.

SAMPLES SHOWING COMPOSITION OF GASES WHEN EQUILIBRIUM HAS BEEN ESTABLISHED AFTER AN EXPLOSION

All the samples discussed in the foregoing sections were taken while strong air movements were still in progress, and it is evident that the composition of the gases may be different when equilibrium has finally been established. However, as soon as strong movements cease another factor enters. The fan is running as a blower during an explosion, but the effect is nullified by the air movements set up by the explosion. As soon as these movements and the cooling of gases cease the air-course door is closed and ventilation is reestablished, which causes the gases to start drifting past the point of sampling at a velocity of 80 to 100 feet per minute. Thus a series of samples taken at E 950 at intervals after the explosion will show the composition of the gases at different points around the explosion zone, as these gases move past the point of sampling. The position of these gases at time intervals before the sample is taken is known in a general way, but can not be definitely stated.

The results of six tests in which the gas samples were collected at intervals varying from 5 seconds to 240 seconds (4 minutes) after the igniting shot was fired are shown in part D of Table 1. In test 633 the explosion reached E 950 station 1.5 seconds after the shot had been fired, and the flame was extinguished by the barrier. The first sample was taken 3.5 seconds later (5 seconds after the shot) and showed incomplete dilution of the gases. The second sample, taken 1 minute after the first, showed a nearly normal content of oxygen. Evidently cooling and contraction of hot gases in the explosion zone had caused an inrush of fresh air from some point outby after sample 1 was taken. However, there was enough carbon monoxide present in this sample to be fatal to life in a short time. The third sample was taken 2 minutes after the second and showed that some of the gases from the explosion that had been carried inby by their own contraction were again being forced outby past the sampling station by action of the ventilating current. A similar relation is found to a greater or less extent in the third sample of each of the other tests.

In tests 634, 636, and 637 the flame stopped at E 1125, E 1100, and E 1025, respectively, and the first sample collected in each test showed little evidence of combustion; deadly amounts of carbon monoxide were present in tests 634 and 637. The subsequent samples indicated that the gases of combustion were being carried out in the air current, and were fairly diluted in comparison with gases sampled during or immediately after the flame.

In tests 639 and 640 the flame reached the point of sampling at E 950; the samples showed dilution after the flame and the subsequent return of some of the gases of combustion from inby points.

These results serve to do little more than to stimulate further investigation. It is desirable to know how far this dilution is carried, and in general to chart the movements and eddying that occur after the flame is extinguished. It is not advisable to make comparison with conditions after an explosion in a large mine with many miles of passageways and rooms. After a widespread explosion in such a mine a long time would be required before fresh air could penetrate to the inner parts, and in fact it would not before the ventilating system was restored unless some temperature difference promoted natural ventilation.

TESTS OF PITTSBURGH COAL DUST UNDER STANDARD METHODS OF IGNITION AND PROPAGATION

Most of the tests of the present series were concerned with the explosibility of various coals, samples of which had been sent to the experimental mine. From 1919 to 1924, inclusive, 156 tests were made, 14 of them in the main entries with mixtures containing Pittsburgh coal dust. Five of the 14 tests had no significance as regards the explosibility of the dust used; the other nine tests check certain results given in Bulletin 167 and are reported herewith.

CHARACTER OF TESTS

Of these nine tests, three were made without dust in the regular test zone and six were standard ignition and propagation tests. The standard test methods are described in detail in Bulletin 167, beginning on page 179, and the arrangements for a propagation test are illustrated in Figure 35, page 220, of that publication. The standard double test zone is indicated in Figure 3 of this bulletin. A short description of the standard test methods is also given herewith.

IGNITION TEST

In the standard ignition test an explosion zone is prepared that extends from the cannon at the face of the main entry (E 1300) outby for 350 feet in the main entry to E 950. The zone also extends across the last cut-through and down the air course to station A 950, a total distance of 400 feet from the cannon (see fig. 3). The mixture of coal dust and shale dust to be tested is distributed throughout this zone at the rate of 1 pound of coal dust per linear foot of entry, except in the section of the main entry inby the last cut-through (E 1250 to E 1300), where the dust is distributed at the rate of 2 pounds of coal dust per linear foot. The dust is distributed one-third each on overhead cross shelves spaced 10 feet apart, on longitudinal side shelves along both sides of the entry, and on the floor. A blown-out shot of 4 pounds of FFF black blasting powder tamped with 3 pounds of slightly damp shale stemming is then fired into the mixture from a cannon at the face of the main entry. If the mixed dust being tested ignites and flame spreads through it to both ends of the test zone it is said that "ignition is obtained." If the flame does not reach both ends of the test zone it is said that "ignition is not obtained." More commonly in an ignition test the flame either spreads entirely through the mixture under test or else is confined to the inner hundred feet of the test zone. The number of ignition tests in which there has been a weak slow flame extending 200 to 300 feet before being extinguished has been very limited.

PROPAGATION TEST

The propagation-test method differs from the ignition-test method only in the character of the dust distributed in the main entry from the cannon to the last cut-through. In the propagation test 100 pounds of pure pulverized (85 per cent 200-mesh) Pittsburgh coal dust is distributed on the side shelves, floor, and one cross shelf in this 50-foot zone. The blown-out shot is fired into this pure coal dust, which ignites and causes projection of a large volume of flame into the mixed dust under test. This mixed dust is distributed in the last cut-through and outby on both entries, as in the ignition test. If the mixed dust ignites and flame is carried to either end of the test zone, it is said that "propagation is obtained." If the flame dies out before reaching both ends of the test zone it is said that "propagation is not obtained." It sometimes happens in a propagation test that the flame will extend to one end of the test zone but not to the other. The practical interpretation of this is that the mixture being tested lies very close to the dividing line of explosibility and should be considered unsafe, as it gave propagation in one zone. When the mixture is definitely nonexplosive, the flame extension may vary from 100 to 300 feet, depending on how close the mixture lies to the explosive limit.

The propagation test is more severe than the ignition test. The starting impulse of the fine coal dust is about the same as would be obtained by the ignition of an explosive gas mixture confined in the same volume.

ANALYSIS OF DUST USED

The Pittsburgh coal dust in the mixtures in the six ignition and propagation tests and the pulverized Pittsburgh coal dust used in the ignition zones of propagation tests had the following average proximate analyses, on an as-received basis:

Average proximate analyses of standard Pittsburgh coal dust

Constituent	Dust used in mixtures	Dust used in ignition zones
	Per cent	*Per cent*
Moisture	2.1	1.9
Volatile matter	36.6	36.4
Fixed carbon	55.4	56.5
Ash	5.9	5.2
Moisture plus ash	8.0	7.1
Ratio of volatile to total combustible	39.8	39.2

The shale dust used in the mixtures was the pit shale described on page 150 of Bulletin 167 and contained an average of 1.7 per cent moisture and 89.5 per cent ash. A proximate analysis does not show the true composition of a shale or clay, because of the water of composition that comes off in the determination of volatile matter. Proximate analyses of shale dust are made for all tests at the experimental mine in order to detect any marked variation in composition, and ultimate analyses are made at intervals to determine the exact composition. A complete analysis of one of the samples used in this series showed 99.6 per cent incombustible material.

SIZE OF DUST USED

The coal dust used in the mixtures in the ignition and propagation tests was so prepared that 99 per cent would pass 20-mesh and 20 per cent would pass 200-mesh. The testing of different-size dusts is described in detail in Bulletin 167, beginning on page 187. Gallery tests described in Bulletin 20[15] and supported by the experimental mine tests described in Chapter V of Bulletin 167 indicated that dust coarser than 20-mesh did not materially enter into or affect an explosion, at least in the early stages. Investigations have shown that in most producing mines an average of about 20 per cent of the combined road and rib dust which passes 20-mesh will pass 200-mesh. On account of these facts, 20-mesh dust of which 20 per cent will pass 200-mesh was most experimented with in tests described in this bulletin.

Pulverized Pittsburgh coal dust was used in the standard ignition zones of propagation tests. Twenty-mesh shale dust was used in the mixtures of five of the six standard tests, and pulverized shale dust was used in the sixth test in order to duplicate conditions in a previous test exactly.[16]

The average size of the coal and shale dust was as follows:

Average sizing tests of coal and shale dusts

Material	Cumulative per cent through—			
	20-mesh	48-mesh	100-mesh	200-mesh
20-mesh coal dust	99.2	75.6	40.2	20.0
Pulverized coal dust	----------	----------	99.2	78.2
20-mesh shale dust	90.9	61.5	40.4	30.0
Pulverized shale dust	----------	----------	99.8	95.6

On account of the difference in method of preparation, the 20-mesh coal dust has a somewhat larger percentage that passes through the 20, 48, and 100 mesh screens than the dust used in similar tests reported on page 208 of Bulletin 167; the additional amount through the respective screens was 3.5, 10.8, and 3.7 per cent, although the same percentage passed through 200-mesh; namely, 20 per cent.

[15] Rice, G. S., and others, The Explosibility of Coal Dust: Bull. 20, Bureau of Mines, 1911, 204 pp.

[16] The effect of different-size shale-dust particles was studied in the previous series of experimental mine tests. See Bull. 167, p. 423.

103804°—27——4

The present dust may then be slightly more explosive; an indication of this was obtained in one test, as will be shown.

The 20-mesh shale dust was "run of crusher," such as had been used in earlier tests. The pulverized shale dust was also similar in size to that used before.

RESULTS OF TESTS WITH PITTSBURGH COAL DUST

The results of the three preliminary tests, three propagation tests, and three ignition tests are given in Table 2.

PROPAGATION TESTS

Tests 519 and 542 were made without any dust, in order to find the length of the cannon flame. It was found to be 25 feet in both tests, which checks the results obtained in test 390 under similar conditions. In test 543 the ignition zone was loaded in the standard manner, but there was no other dust present. The flame from the ignition zone extended 50 feet into the dustless zone, or 100 feet from the cannon; the same result was obtained in test 376, made nearly three years before.

In tests 495 and 515 a mixture of 50 per cent coal dust and 50 per cent 20-mesh shale dust was used, and propagation was obtained in both. In these tests the pressures are much the same and the flame velocities are of the same order as those obtained in test 277, made on January 28, 1916. The conditions in test 277 differed slightly from tests 495 and 515, in that pulverized shale was used.

It will be noted that the pressures produced and the velocities were low. It might have been expected that with 20-mesh shale the mixture would cause somewhat more violence or higher velocities, but there is no marked difference in the results obtained.

Test 616 was an exact duplicate of test 317. The flame in test 616 was 50 feet longer on the entry and 75 feet longer on the air course than that in test 317, indicating that the mixture was slightly more explosive. This may be due to the fact that although the percentage of coal dust through 200-mesh was the same in both tests a larger amount of the coal dust passed through the coarser screens, particularly 48 and 100 mesh, in test 616 than in test 317. However, the matter can not be considered settled on the evidence of a single test, and more closely defined figures of the relative explosibility of dusts with different proportions of sizes coarser than 200-mesh remain to be determined under test conditions in the experimental mine. From all the propagation tests it can be concluded that the results obtained in 1920 were practically the same as those obtained three years before, and that the propagation-test method yields uniform and constant results.

TABLE 2.—*Results of standard tests of mixtures of 20-mesh, 20 per cent 200-mesh, Pittsburgh coal dust and pit-shale dust, with no gas present*

PROPAGATION TESTS

Test	Date	Size of shale dust used	Ratio of coal dust to shale dust in mixture	Mixed dusts: Calculated incombustible content, per cent	Mixed dusts: Rate of loading, pounds per foot	Mixed dusts: Total loading, pounds	Records obtained in entry or air course	Maximum pressure, pounds per square inch: Station 1150	Maximum pressure, pounds per square inch: Station 950	Time of tin-foil rupture at station E 1250, second	Flame velocity between stations, feet per second: Station 1250 to station 1150	Flame velocity between stations, feet per second: Station 1150 to station 1050	Flame velocity between stations, feet per second: Station 1050 to station 950	Length of flame measured from cannon, feet	Remarks
519	Nov. 12, 1919	(1)	(1)	(1)	(1)	(1)	Entry		[2] 4					25	Test to determine length of flame from cannon only.
							Air course		[2] 2						
542	Jan. 9, 1920	(1)	(1)	(1)	(1)	(1)	Entry	[2] 3	[2] 3					25	Do.
							Air course	[2] 4	[2] 3						
543	do	(1)	(1)	(1)	(1)	(1)	Entry	[3] 6	[3] 5	0.383				100	Test to determine length of flame from ignition zone in a dustless zone outby.
							Air course	[3] 6	[3] 3					100	
495	Feb. 28, 1919	20-mesh	50:50	54.0	2.00	1,300	Entry	3	3	.397	116	113	56	(4)	Propagation obtained.
							Air course	3	3			219	510	(4)	
515	Nov. 4, 1919	do	50:50	54.0	2.00	1,300	Entry	3	4	.292		111	121	(4)	Do.
							Air course	3	3				227	(4)	
616	Dec. 26, 1923	Pulverized	40:60	63.2	2.50	1,625	Entry		1					200	Propagation not obtained.
							Air course	1	1					275	

IGNITION TESTS

Test	Date	Size of shale dust used	Ratio of coal dust to shale dust in mixture	Calculated incombustible content, per cent	Rate of loading, pounds per foot	Total loading, pounds	Records obtained in entry or air course	Station 1150	Station 950	Time of tin-foil rupture at station E 1250, second	Station 1250 to station 1150	Station 1150 to station 1050	Station 1050 to station 950	Length of flame measured from cannon, feet	Remarks
520	Nov. 14, 1919	20-mesh	70:30	35.6	1.43	1,071	Entry	6	6	0.727	91	160	617	(4)	Ignition obtained.
							Air course	5	6			199	329	(4)	
517	Nov. 10, 1919	do	65:35	40.2	1.54	1,155	Entry	1	1	.725				125	Ignition not obtained.
							Air course	1	½					150	
516	Nov. 6, 1919	do	60:40	44.8	1.67	1,250	Entry	1	1	.726				100	Do.
							Air course	1						125	

[1] Mixed dust not used in this test.
[2] Pressure caused by shock wave.
[3] Pressure due to burning coal dust in ignition zone.
[4] Flame extended through zone.

IGNITION TESTS

In test 520 ignition was obtained with a mixture of 70 per cent 20-mesh, 20 per cent 200-mesh coal dust, and 30 per cent 20-mesh pit-shale dust. This mixture had been tried in test 344 about three years before, and ignition had been obtained at that time, but the velocities and pressures were much higher in the earlier test than in test 520. In test 517 ignition was not obtained with a mixture of 65 per cent coal dust and 35 per cent shale dust, as the maximum flame extension was 100 feet. A test of this mixture had not been made before. In test 516 a mixture of 60 per cent coal dust and 40 per cent shale dust was used. Ignition was not obtained, as the flame extended a maximum distance of 75 feet. This mixture had been used in tests 328 and 349 on May 24 and November 22, 1916. In the first of these tests the flame had extended a maximum distance of 175 feet, and in the second had extended entirely through the zones. Why it should be more difficult to ignite a given mixture in November, 1919, than it was three years before is not evident, particularly when no similar change was observed in results of propagation tests. As the difference between an ignition and a propagation test is, as regards the mixed dust, a difference in the violence of the source of ignition, it may be that certain factors ordinarily neglected or duplicated imperfectly are important when sources of ignition weak in dust raising or igniting power are employed, but are obscured when the violence of the igniting source passes a certain point. As this discussion deals with differences of about 5 per cent of incombustible in the mixture, and a violent start can be given an explosion through the ignition of gas or a zone of fine, pure dust, the question of relative violence is more along the line of pure research than of practical tests of mine conditions. Therefore, study of this matter has been postponed, pending the completion of work on more important points.

TESTS OF DUSTS OF COALS OTHER THAN PITTSBURGH

As previously stated, the testing of dusts prepared from samples of coal shipped to the experimental mine from producing mines operating in various beds was the principal explosibility testing problem in hand from 1919 to 1924. The methods of sampling and of making an explosion-hazard investigation of a specific mine, and the methods of explosion testing were reported in detail in Chapter VI of Bulletin 167, beginning on page 218. These methods had been fully developed in 1918 and later work was primarily an extension of the number of coals tested; 13 different samples had been received from 1919 to 1924. Investigations of different mines brought out the fact that if dust passing a 20-mesh screen is used as a basis of comparison, road-dust samples taken in a majority of the operating mines will show an average of less than 20 per cent through a 200-mesh screen. The rib dust and roof dust will average about 40 to 50 per cent through 200-mesh, but unless there are gobbed side walls or much timber on which the fine dust can lodge, the average size of all the dust is not much above 20 per cent through 200-mesh. Dust from timbers near the roof is usually very fine and pure, and frequently will show 85 per cent through 200-mesh. On account of its size and place of lodgment, such dust is the most dangerous in a mine. As an indication of the general conditions found in commercial mines, it may be stated that of 13 samples tested in the present work, 20-mesh dust of which 20 per cent would pass 200-mesh was used in tests of 11 dusts as being nearest the size of the dust found in the respective mines.

It is recognized that the most difficult part of explosibility testing is to determine the actual conditions in producing mines and to reproduce them in the experimental mine. The difficulty lies in the extreme variations found not only between different mines, but within a single mine. For example, if an entry had a damp floor and the material thereon were coarse, an explosion would derive most of its fuel from the dust on the ribs and roof, particularly where timbers or other flat surfaces supplied space on which float dust could settle. If there were enough pure coal dust on the ribs and timbers to support an explosion without additional coal dust from the floor, a condition would be realized that might make a general average of road and rib dust samples erroneous, even if a large number were tested. On account of its size and position, the rib and timber dust would be the controlling factor in an explosion. Manifestly, discriminating judgment is required in sampling.[17] The condition just described is not difficult to overcome when the area is rock-dusted, because any ledge or surface that will support coal dust can also support rock dust. The replacement of coal dust with rock dust is the desired end, for then an incipient explosion instead of finding fuel is met with a cloud of incombustible dust which quickly extinguishes it.

CHARACTER OF TESTS

The standard test zone at the inner end of the main entries is shown in Figure 3. As stated, two classes of tests—ignition and propagation—are made. In an ignition test a blown-out shot of 4 pounds of FFF black blasting powder is fired directly into the mixed dust under test. If the dust ignites and the flame travels to both ends of the zone, it is said that ignition is obtained. If the flame dies out before reaching both ends of the zone, ignition is not obtained.

---

17 The British official orders now require that dust from the floor, ribs, and roof (including roof timber) shall all contain less than 50 per cent combustible material, thus requiring separate sampling and analysis.

In the propagation test the blown-out shot is fired into a 50-foot zone of pulverized Pittsburgh coal dust (about 85 per cent through 200-mesh). An explosion develops in this dust which projects itself into the mixed dust immediately outby. If this mixed dust sustains the explosion and flame travels to both ends of the mixed dust zone it is said that propagation is obtained. If the flame is extinguished before it reaches both ends of the mixed dust zone, it is said that propagation is not obtained.

A mixture that is definitely explosive under these tests gives increasing pressures and velocities as the flame travels through it. The propagation test is the more severe of the two, and is the one more nearly representing actual mine conditions, where a gas explosion may serve as a violent start of a dust explosion, or a longer zone of coal dust less explosive than the pulverized Pittsburgh coal dust may be found near the face. The purpose in making the ignition tests is to satisfy the mine management of a bituminous coal mine that the coal is explosive without the aid of gas or of Pittsburgh dust; moreover it serves as a useful check on the propagation tests. The latter require on the average 15 per cent more incombustible to prevent an explosion passing through the mixture than the ignition tests of the same sizes.

DESCRIPTION AND SOURCE OF COALS TESTED

On page 222 of Bulletin 167, 19 coals are listed which had been tested up to the end of 1918. The 13 coals tested subsequently are listed in Table 3 below, arranged in descending order of the ratio of volatile to total combustible.

TABLE 3.—*Coal dusts tested, listed in descending order of ratio of volatile matter to total combustible*

No.	Designation and kind of coal	Source	
		District	County and State
1	No. 5 bed, subbituminous	Gallup	McKinley, N. Mex.
2	Wadge bed, bituminous	Yampa	Routt, Colo.
3	Pinnacle or Argo bed, bituminous	do	Do.
4	Raton bed, bituminous [1]	Raton-Dawson	Colfax, N. Mex.
5	No. 1 bed, bituminous	Rock Springs	Sweetwater, Wyo.
6	No. 5 bed (No. 1 sample), bituminous	Southern Illinois	Saline, Ill.
7	No. 9 bed, bituminous	Western Kentucky	Union, Ky.
8	No. 5 bed (No. 2 sample), bituminous	Southern Illinois	Saline, Ill.
9	No. 5 bed (No. 3 sample), bituminous	do	Do.
10	Jagger bed, bituminous	Warrior River	Walker, Ala.
11	Silkstone bed, bituminous		Yorkshire, England.
12	Nickel Plate bed, bituminous [1]	Warrior River	Jefferson, Ala.
13	Beckley or War Creek bed, semibituminous	Tug River	McDowell, W. Va.

[1] Is designated as a "coking coal," although samples 6, 7, 8, 9, 10, and 11 will also coke more or less.

ROCK DUST USED IN TESTS

Shale was used as the incombustible dust in the mixtures for all explosion tests of the coals listed in Table 3 and described in this section. This shale is mined in what was first a pit but is now a short drift entry in the side of the hill 62 feet below the elevation of the Pittsburgh coal, and is commonly known as pit shale to distinguish it from draw slate, which is called roof shale. A complete analysis of this shale was given on page 150 of Bulletin 167. Briefly, the shale is a mixture of silicates of aluminum and iron with free silica.[18] There is a small proportion of carbonates of lime and magnesia and very little combustible matter. It has been noticed that the proportion of carbonates has increased as the drift has gone under heavier cover and streaks of sandstone have appeared in the shale. The sandstone is undesirable, and it will be necessary to follow the bed along the crop line rather than drift deeper into the hill.

The dust used in the present tests averaged 99 per cent incombustible, of which 1.4 per cent was moisture. It was used directly, as it came from the crusher, and averaged 94.3 per cent through 20-mesh, 68.7 per cent through 48-mesh, 43.6 per cent through 100-mesh, and 32.9 per cent through 200-mesh. The coarsest sample used contained 30.2 per cent and the finest 40.7 per cent of 200-mesh dust. Pulverized shale was used in the few tests made with pulverized coal. Shale of this size contains about 95 per cent of 200-mesh dust.

PITTSBURGH COAL DUST USED IN IGNITION ZONES OF PROPAGATION TESTS

The fine Pittsburgh coal dust used in front of the cannon in propagation tests was pulverized from lump coal taken from the experimental mine and used as it came from the pulverizer. The chemical composition of the dust was quite uniform over the entire period and averaged 6.9 per cent of moisture plus ash with a ratio of volatile to total combustible of 40. The sizing of the dust showed an average of 99.3 per cent through 100-mesh and 83.8 per cent through 200-mesh, with some variation in different samples. The 200-mesh dust content varied from 74.4 per cent to 92.4 per cent, but there has been no indication that this variation affected in any way the results obtained from the propagation tests.

---

[18] This shale is light yellow when dried and crushed. Although not gritty, it contains too much free silica for rock-dusting purposes in commercial mines, as it might be injurious to health if breathed constantly. A tentative limit for free silica in rock dust has been set at 25 per cent.

EXPLOSIBILITY TESTS OF COAL DUST FROM NO. 5 BED, McKINLEY COUNTY, N. MEX.

Six ignition tests and five propagation tests were made of 20-mesh dust prepared from a 4-ton sample of run-of-mine coal obtained from a mine working the No. 5 bed in McKinley County, N. Mex. The dust was so prepared that 40 per cent would pass 200-mesh, which was the standard size next finer than the average size of the road and rib dusts collected in the mine.

CONDITIONS IN MINE WHERE SAMPLE WAS OBTAINED

A standard explosion-hazard investigation of the mine was made. Four standard face samples of coal were taken; analyses are given in Table 4.

TABLE 4.—*Analyses of face samples of coal from a New Mexico mine working No. 5 bed (subbituminous coal)*

Laboratory No.	Coal as received				Moisture plus ash	Ratio, $\frac{V}{V+FC}$
	Moisture	Volatile matter	Fixed carbon	Ash		
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	
32338	12.2	37.9	41.7	8.2	20.4	47.6
32339	13.1	37.7	41.3	7.9	21.0	47.7
32340	14.4	36.4	41.3	7.9	22.3	46.9
32341	13.0	39.1	40.6	7.3	20.3	49.0

The analysis of a composite of these samples is as follows:

Results of analyses of composite sample

[Coal as received]

Proximate analysis:	Per cent	Ultimate analysis:	Per cent
Moisture	13.2	Hydrogen	5.9
Volatile matter	37.7	Carbon	62.0
Fixed carbon	41.2	Nitrogen	1.0
Ash	7.9	Oxygen	22.7
Moisture plus ash	21.1	Sulphur	.5
Ratio of volatile to total combustible	47.9	Ash	7.9

Seven standard road-dust and rib-dust samples were collected. The results of the analyses and sizing tests of these samples are given in Table 5.

TABLE 5.—*Analyses and sizing tests of road dust and rib dust from a New Mexico mine working No. 5 bed*

Laboratory No.	Kind of dust	Analysis as received				Moisture plus ash	Percentage of 20-mesh material through—	
		Moisture	Volatile matter	Fixed carbon	Ash		100-mesh screen	200-mesh screen
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*		
32344	Road dust	10.1	25.2	23.7	41.0	51.1	43.9	31.7
32346	do	12.0	24.9	22.9	40.2	52.2	36.8	22.0
32343	do	13.6	27.5	22.2	36.7	50.3	32.1	19.9
32345	do	8.1	18.5	15.7	57.7	65.8	41.7	26.4
32348	Rib dust	9.3	26.7	21.2	42.8	52.0	61.5	48.7
32849	do	9.1	18.5	15.1	57.3	66.4	34.9	21.2
32347	do	10.8	34.3	35.0	19.9	30.7	70.7	47.6

When the weights of the corresponding samples of road and rib dust are considered, the general average of incombustible content is 53.8 per cent moisture plus ash, and the average size is 27.8 per cent through a 200-mesh sieve.

Three samples of the mine air were taken in different parts of the return airways. These contained a maximum of 0.04 per cent methane, showing that as far as the entire mine was concerned the normal ventilation was adequate. However, in mines in this district local accumulations of methane are occasionally liberated in face working or from falls of roof.

DETAILS OF EXPLOSION TESTS

Procedure and results.—Six ignition tests were made with 20-mesh dust—three without gas and three with gas in the air current. Five propagation tests were made with 20-mesh dust—two without gas and three with gas in the air current.

The average analysis of 20-mesh coal dust from No. 5 bed just before mixing for the tests was as follows:

Average analysis of 20-mesh coal dust from No. 5 bed

Constituents:	Per cent
Moisture	10.9
Volatile matter	38.2
Fixed carbon	42.6
Ash	8.3
Moisture plus ash	19.2
Ratio of volatile to total combustible	47.3

The average of the sizing tests of the coal dust was as follows: Through 20-mesh, 99.1 per cent; through 48-mesh, 77.3 per cent; through 100-mesh, 57.2 per cent; and through 200-mesh, 40 per cent.

The results of the explosion tests are given in Table 6.

TABLE 6.—*Results of standard tests of 20-mesh, 40 per cent 200-mesh, coal dust from No. 5 bed, McKinley County, N. Mex.*

IGNITION TESTS

Test No.	Date, 1920	Ratio of coal dust to shale dust in mixture	Mixed dust: Calculated incombustible content, per cent	Mixed dust: Rate of loading, pounds per foot	Mixed dust: Total loading, pounds	Natural gas used, per cent	Records obtained in entry or air course	Maximum pressure, pounds per square inch: Station 1150	Maximum pressure, pounds per square inch: Station 950	Time of tin-foil rupture at station E1250, second	Flame velocity between stations, feet per second: Station 1250 to station 1150	Flame velocity: Station 1150 to station 1050	Flame velocity: Station 1050 to station 950	Length of flame measured from cannon, feet	Remarks
546	Jan. 16	80:20	35.3	1.25	937.5	0.0	Entry	32	39	0.477	222	2,000	2,083	(1)	Ignition obtained.
							Air course	35	69			602	2,778	(1)	
556	Feb. 12	60:40	51.5	1.67	1,250	.0	Entry	17	19	.557	109	351	806	(1)	Do.
							Air course	14	22			495	1,370	(1)	
547	Jan. 19	50:50	59.6	2.00	1,500	.0	Entry	2	1	.763	28			100	Ignition not obtained.
							Air course	1	1					225	
548	Jan. 22	40:60	67.7	2.50	1,875	.8	Entry	2	1	.813	44			175	Do.
							Air course	1	1			73		300	
550	Jan. 28	30:70	75.8	3.33	2,500	1.6	Entry	1	1	.899				75	Do.
							Air course	1	1					150	
555	Feb. 10	30:70	75.8	3.33	2,500	2.1	Entry	1	1				[2] 95	(1)	Ignition obtained.
							Air course	2	1			136	87	(1)	

PROPAGATION TESTS

Test No.	Date, 1920	Ratio of coal dust to shale dust in mixture	Mixed dust: Calculated incombustible content, per cent	Mixed dust: Rate of loading, pounds per foot	Mixed dust: Total loading, pounds	Natural gas used, per cent	Records obtained in entry or air course	Maximum pressure, pounds per square inch: Station 1150	Maximum pressure, pounds per square inch: Station 950	Time of tin-foil rupture at station E1250, second	Flame velocity between stations, feet per second: Station 1250 to station 1150	Flame velocity: Station 1150 to station 1050	Flame velocity: Station 1050 to station 950	Length of flame measured from cannon, feet	Remarks
549	Jan. 26	40:60	67.7	2.50	1,625	0.0	Entry	8	8	0.314	133	549	351	(1)	Propagation obtained.
							Air course	9	9			249	1,053	(1)	
551	Jan. 28	30:70	75.8	3.33	2,167	.0	Entry	1	1					175	Propagation not obtained.
							Air course	1	1					275	
554	Feb. 6	25:75	79.8	4.00	2,600	1.2	Entry	1	1	.293	44	55		275	Do.
							Air course	1	1			97		325	
552	Jan. 30	25:75	79.8	4.00	2,600	1.4	Entry	3	3	.278	177	125	95	(1)	Propagation obtained.
							Air course	4	4			190	303	(1)	
553	Feb. 4	20:80	83.9	5.00	3,250	1.9	Entry	1	1	.270	42			175	Propagation not obtained.
							Air course	1	1			62		325	

[1] Flame extended through zones.

[2] Station 1150 to station 950.

Discussion of ignition tests.—In test 546 rapid and violent ignition was obtained with a mixture containing 35.3 per cent incombustible (20 per cent shale). Ignition of moderate violence was obtained in test 556 with a mixture containing 51.5 per cent incombustible (40 per cent shale). Ignition was not obtained in test 547 with a mixture containing 59.6 per cent incombustible (50 per cent shale), but the flame was extended 225 feet in the air course, and there is very little margin of safety in this mixture. No gas was present in any of the foregoing tests.

In test 548 a mixture containing 67.7 per cent incombustible (60 per cent shale) did not "ignite" with 0.8 per cent natural gas present, but the flame extended 300 feet into the 400-foot test zone, and ignition would undoubtedly have been obtained had there been 1 per cent gas present. A mixture containing 75.8 per cent incombustible (70 per cent shale) was tried with 1.6 per cent of gas in test 550 and with 2.1 per cent in test 555. Ignition was not obtained in the former, but a weak, slow explosion was obtained in the latter. The mixture is close to the border line with 2 per cent gas, and a few per cent more of shale would prevent "ignition."

Discussion of propagation tests.—Propagation was obtained in test 549 with a mixture containing 67.7 per cent incombustible (60 per cent shale), but was not obtained in test 551 with a mixture containing 75.8 per cent incombustible (70 per cent shale); the flame extended a maximum distance of 275 feet in the latter test. No gas was present in either test.

A mixture containing 79.8 per cent incombustible (75 per cent shale) was tried with 1.2 per cent gas in test 554 and 1.4 per cent gas in test 552. Propagation was not obtained with the lower percentage of gas, although the flame extended 325 feet, or to a point only 75 feet from the end of the 400-foot dust zone. With the higher percentage of gas complete propagation was obtained. Propagation was not obtained in test 553 with a mixture containing 83.9 per cent incombustible (80 per cent shale) with 1.9 per cent gas in the air. The flame extended 325 feet in the 400-foot air-course zone in this test, and the mixture is very close to the border line of explosibility with 2 per cent of gas present.

CONCLUSIONS ON EXPLOSIBILITY OF DUST FROM NO. 5 BED

The tests show that this dust is explosive in the size found in the mine, as might be inferred from the high ratio of volatile to total combustible (47.3 per cent as tested). The presence of nearly 11 per cent moisture in the coal apparently does not counteract the high proportion of volatile matter, and the dust is slightly more explosive than Pittsburgh coal dust, which has a volatile ratio of 40 per cent and contains about 2 per cent moisture.

The amount of incombustible material necessary in mixtures of the 20-mesh coal dust, of which 40 per cent will pass 200-mesh, to prevent ignition and propagation under various conditions is as follows:

Incombustible needed to prevent ignition and propagation of coal dust from No. 5 bed

Condition	Gas present	Incombustible in mixture	Rock dust in mixture
	Per cent	*Per cent*	*Per cent*
Nonignition	0	60	50
Do	1	70	63
Do	2	80	75
Nonpropagation	0	76	70
Do	1	80	75
Do	2	85	81

These factors are based on the assumption that the coal dust will contain all the moisture (10 to 11 per cent) which it had as solid coal. If the amount of moisture were reduced from any cause, the amount of incombustible required would be somewhat increased.

Application to field conditions.—There was little gas in the mine from which this coal came, and the road and rib dust samples averaged about 30 per cent through 200-mesh, whereas the coal dust tested showed 40 per cent through 200-mesh. The fact that the dust in the mine is not as fine as that tested might be taken to offset small quantities of gas (up to 0.25 per cent) and it would then be necessary to have 76 per cent incombustible in the dust to prevent propagation of an explosion. Six of the seven road dusts and rib dusts ranged from 50 to 66 per cent moisture plus ash; the seventh had only 31 per cent. All needed additional incombustible material (rock dust) to make them nonexplosive. The maximum weight of rock dust needed would be with the rib dust having only 31 per cent moisture plus ash, which would require twice as much rock dust as there was rib dust present. The proper method is to apply an excess amount and then determine the actual percentage of incombustible at intervals thereafter. When it falls to the danger line additional rock dust is necessary.

EXPLOSIBILITY TESTS OF COAL DUST FROM WADGE BED, ROUTT COUNTY, COLO.

Six ignition tests and five propagation tests were made with 20-mesh dust prepared from a 4-ton sample of run-of-mine coal from a mine working the Wadge bed in Routt County, Colo. The dust was so prepared that 20 per cent would pass 200-mesh, which was the average size of the road and rib dusts collected in the mine.

CONDITIONS IN MINE WHERE SAMPLE WAS OBTAINED

A standard explosion-hazard investigation of the mine was made. Eight standard face samples of coal were taken and analyses of these are given in Table 7.

TABLE 7.—*Analyses of face samples of coal from a Colorado mine working the Wadge bed*

Laboratory No.	Coal as received				Moisture plus ash	Ratio, $\frac{V}{V+FC}$
	Moisture	Volatile matter	Fixed carbon	Ash		
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	
31199	10.4	38.2	46.5	4.9	15.3	45.1
31200	12.4	37.6	44.2	5.8	18.2	46.0
31201	10.6	37.6	46.2	5.6	16.2	44.8
31202	11.4	37.2	45.4	6.0	17.4	45.0
31203	10.8	37.2	45.3	6.7	17.5	45.0
31204	9.9	38.0	46.3	5.8	15.7	45.1
31205	11.3	38.3	46.4	4.0	15.3	45.2
31206	10.8	37.8	45.3	6.1	16.9	45.5

Analyses of a composite of these samples are as follows:

Results of analyses of composite sample

[Coal as received. Samples placed in cans and sealed at points of gathering in mine]

Proximate analysis:	Per cent	Ultimate analysis:	Per cent
Moisture	11.0	Hydrogen	5.8
Volatile matter	37.7	Carbon	65.3
Fixed carbon	45.7	Nitrogen	1.6
Ash	5.6	Oxygen	21.3
Moisture plus ash	16.6	Sulphur	.4
Ratio of volatile to total combustible	45.2	Ash	5.6

Twelve road-dust and an equal number of rib-dust samples were collected. The results of the analyses and sizing tests of these samples are given in Table 8.

TABLE 8.—*Analyses and sizing tests of road dust and rib dust from a Colorado mine working the Wadge bed*

Laboratory No.	Kind of dust	Analysis as received				Moisture plus ash	Percentage of 20-mesh material passing through—	
		Moisture	Volatile matter	Fixed carbon	Ash		100-mesh screen	200-mesh screen
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*		
31220	Road dust	17.9	28.7	40.1	13.3	31.2	7.6	3.6
31221	do	16.0	29.5	36.4	18.1	34.1	12.6	4.4
31222	do	20.1	29.8	38.7	11.4	31.5	12.4	6.7
31229	do	18.8	14.1	21.2	45.9	64.7	24.6	14.1
31223	do	14.8	29.9	39.6	15.7	30.5	32.2	15.9
31224	do	8.2	26.1	34.7	31.0	39.2	31.8	20.9
31225	do	10.5	29.1	36.3	24.1	34.6	38.7	25.7
31226	do	12.0	20.6	25.1	42.3	54.3	15.7	6.8
31227	do	10.0	26.7	32.7	30.6	40.6	35.1	22.3
31228	do	9.3	20.3	24.4	46.0	55.3	36.5	22.2
31230	do	8.4	25.4	28.6	37.6	46.0	42.0	27.6
31231	do	9.1	27.9	33.4	29.6	38.7	44.0	30.0
31209	Rib dust	14.0	31.2	33.1	21.7	35.7	59.3	34.6
31210	do	17.0	29.6	36.1	17.3	34.3	64.7	45.7
31211	do	18.3	30.9	36.5	14.3	32.6	62.8	33.9
31217	do	12.7	31.5	41.7	14.1	26.8	67.4	44.1
31232	do	12.7	32.7	38.1	16.5	29.2	44.8	29.8
31212	do	10.5	31.1	39.5	18.9	29.4	73.8	59.9
31213	do	11.4	32.4	41.4	14.8	26.2	78.0	59.1
31214	do	8.7	25.0	27.8	38.5	47.2	73.4	57.2
31215	do	11.6	28.4	31.0	29.0	40.6	74.5	58.7
31216	do	10.2	27.8	33.9	28.1	38.3	64.2	51.1
31219	do	9.0	31.6	39.4	20.0	29.0	48.1	30.2
31218	do	7.5	28.0	33.2	31.3	38.8	68.5	57.7

When the weights of the corresponding road and rib dust samples are taken into consideration, the general average for total incombustible is 40.9 per cent moisture plus ash, and for size, 20 per cent through a 200-mesh sieve.

Six samples of the mine air were taken in different parts of the mine. The return air showed a maximum of 0.02 per cent methane. Samples taken in the last cut-throughs between entries showed a maximum of 0.06 per cent methane with 7,900 feet of air moving. At another point with no air there was 0.02 per cent methane. The mine was virtually free of fire damp at the time of the investigation, but it is liable to be encountered

DETAILS OF EXPLOSION TESTS

Procedure and results.—Six ignition tests were made with 20-mesh dust, two without gas and four with gas in the air current. Five propagation tests were made with 20-mesh dust, two without gas and three with gas present.

The average analysis of 20-mesh coal dust from the Wadge bed just before it was mixed for the tests was as follows:

Average analysis of 20-mesh coal dust from the Wadge bed

[Coal as received. From bulk sample which lost some moisture in transit and a little in preparation]

Constituents:	Per cent
Moisture	9.3
Volatile matter	37.8
Fixed carbon	46.2
Ash	6.7
Moisture plus ash	16.0
Ratio of volatile to total combustible	45.0

The average of the sizing tests of the coal dust was as follows: Through 20-mesh, 96.5 per cent; through 48-mesh, 61 per cent; through 100-mesh, 34.9 per cent; and through 200-mesh, 20 per cent. The results of the explosion tests are given in Table 9.

Discussion of ignition tests.—In test 505 pure 20-mesh coal dust from the Wadge bed was used. Three per cent water was added to bring the moisture content of the dust up to 11 per cent, the same as in the mine. Ignition was obtained, the explosion being of moderate violence. In test 506 ignition was not obtained with a mixture containing 32.8 per cent incombustible (20 per cent shale) with no gas present, but it was obtained in test 508 with a similar mixture and 1 per cent gas present; the resultant explosion was strong and rapid. Ignition was also obtained in test 510 with a mixture containing 41.2 per cent incombustible (30 per cent shale) with 1 per cent gas in the air. This explosion was slow and weak; 5 per cent more shale would probably prevent ignition. Ignition was not obtained in test 512 with a mixture containing 49.6 per cent incombustible (40 per cent shale), with 0.8 per cent gas in the air. Ignition was not obtained in test 513 with a mixture containing 58 per cent incombustible (50 per cent shale), with 1.7 per cent gas in the air. The flame extended only 75 feet in test 513 and the mixture might be safe with 2 per cent gas; at any rate, a mixture containing 60 per cent incombustible would probably be safe under these conditions.

Discussion of propagation tests.—Complete propagation was not obtained in test 504 with a mixture containing 49.6 per cent incombustible (40 per cent shale), as the flame traveled entirely through the dust zone in the air course but stopped 25 feet short in the main entry. No gas was present in this test. This mixture is very close to the border line and must be classed as explosive. Propagation was not obtained in test 503 with a mixture containing 58 per cent incombustible (50 per cent shale), with no gas present. The 50–50 coal-shale mixture was tried in test 507 with 1.3 per cent gas present, and an explosion of moderate violence resulted. This mixture is not safe with 1 per cent of gas present. A mixture containing 66.4 per cent incombustible (60 per cent shale) was tried with 0.8 per cent

TABLE 9.—*Results of standard tests of 20-mesh, 20 per cent 200-mesh, coal dust from the Wadge bed, Routt County, Colo.*

IGNITION TESTS

Test No.	Date, 1919	Ratio of coal dust to shale dust in mixture	Mixed dust: Calculated incombustible content, per cent	Mixed dust: Rate of loading, pounds per foot	Mixed dust: Total loading, pounds	Natural gas used, per cent	Records obtained in entry or air course	Maximum pressure, pounds per square inch: Station 1150	Maximum pressure, pounds per square inch: Station 950	Time of tin-foil rupture at station E1250, seconds	Flame velocity between stations, feet per second: Station 1250 to station 1150	Flame velocity: Station 1150 to station 1050	Flame velocity: Station 1050 to station 950	Length of flame measured from cannon, feet	Remarks
505	Apr. 9	[1] 97:30	18.5	1.00	750	0.0	Entry	8	9			229	990	(2)	Ignition obtained.
							Air course	7	7			261	885	(2)	
506	Apr. 11	80:20	32.8	1.25	937.5	.0	Entry	2	2	1.578				100	Ignition not obtained.
							Air course	2	1					175	
508	Apr. 18	80:20	32.8	1.25	937.5	1.0	Entry	14	15	.571	75	794	1,250	(2)	Ignition obtained.
							Air course	10	15			312	629	(2)	
510	Apr. 23	70:30	41.2	1.43	1,072.5	1.0	Entry	3	2			124	185	(2)	Do.
							Air course	3	3			140	210	(2)	
512	Apr. 25	60:40	49.6	1.67	1,250	.8	Entry	1	1	3.448				75	Ignition not obtained.
							Air course	1	1					150	
513	do	50:50	58.0	2.00	[3] 400	1.7	Entry	1	1					75	Do.
							Air course	1	1					75	

PROPAGATION TESTS

Test No.	Date, 1919	Ratio of coal dust to shale dust in mixture	Mixed dust: Calculated incombustible content, per cent	Mixed dust: Rate of loading, pounds per foot	Mixed dust: Total loading, pounds	Natural gas used, per cent	Records obtained in entry or air course	Maximum pressure, pounds per square inch: Station 1150	Maximum pressure, pounds per square inch: Station 950	Time of tin-foil rupture at station E1250, seconds	Flame velocity between stations, feet per second: Station 1250 to station 1150	Flame velocity: Station 1150 to station 1050	Flame velocity: Station 1050 to station 950	Length of flame measured from cannon, feet	Remarks
504	Apr. 4	60:40	49.6	1.67	1,083	0.0	Entry	(4)						325	Complete propagation not obtained.
							Air course	2	2					(2)	
503	Apr. 2	50:50	58.0	2.00	1,300	.0	Entry	1	1	.618	49			175	Propagation not obtained.
							Air course	1	2					275	
507	Apr. 16	50:50	58.0	2.00	1,300	1.3	Entry	7	7	.168	109	407	228	(2)	Propagation obtained.
							Air course	5	5			231	870	(2)	
511	Apr. 24	40:60	66.4	2.50	1,625	.8	Entry	2	1	.312	70			200	Propagation not obtained.
							Air course	1	2					250	
509	Apr. 21	40:60	66.4	2.50	1,625	2.0	Entry	9	8	.303	211	221	470	(2)	Propagation obtained.
							Air course	8	9			295	2,128	(2)	

[1] Mixture in this test was pure coal dust and water.
[2] Flame extended through zone.
[3] Dust loaded to E1200 and A1250 only, 100 feet from the cannon.
[4] No pressure records obtained in entry and no tin-foil records obtained in either entry or air course.

gas in test 511 and with 2 per cent gas in test 509. Propagation was not obtained with 0.8 per cent gas, but the flame extension was 250 feet, and this mixture would be very close to the border line with 1 per cent gas. With 2 per cent gas a moderately strong explosion was obtained.

CONCLUSIONS ON EXPLOSIBILITY OF DUST FROM WADGE BED

Tests show that this dust is explosive in the size found in the mine. Dust from the Wadge bed has a higher ratio of volatile to total combustible (45 per cent as tested) and about 7 per cent more moisture than Pittsburgh coal. The dust is slightly less explosive than Pittsburgh coal dust of the same size.

The amount of incombustible material necessary in a mixture of the 20-mesh coal dust, of which 20 per cent passes 200-mesh, to prevent ignition and propagation under various conditions is as follows:

Incombustible needed to prevent ignition or propagation of coal dust from the Wadge bed

Condition	Gas present	Incombustible in mixture	Rock dust in mixture
	Per cent	*Per cent*	*Per cent*
Nonignition	0	33	20
Do	1	45	35
Do	2	60	52
Nonpropagation	0	58	50
Do	1	68	62
Do	2	76	71

These figures are based on the assumption that the coal dust will contain as much moisture as that in the mine.[18a] As the coal did not lose any great amount of its moisture in passing through the crushing machinery at the experimental mine, probably the mine dust will not lose any moisture under ordinary conditions.

Application to field conditions.—The mine from which this sample came was practically free of methane at the time of the investigation. It is necessary under these conditions to have 58 per cent of incombustible material in the road and rib dusts to prevent propagation of an explosion. Only one of the 24 road and rib dusts had more than this amount of incombustible material; the others ranged from 26 to 55 per cent. Applying an amount of rock dust equal to the weight of the road and rib dust would raise the incombustible content of them all above the dividing line, and if this was done throughout the mine an explosion could not take place. The application of a heavy coating of rock dust would probably raise the incombustible

[18a] See analyses, p. 49.

content of the road and rib dusts above 80 per cent and produce safe conditions for a period, depending upon the rate at which fresh coal dust accumulated.

EXPLOSIBILITY TESTS OF COAL DUST FROM PINNACLE OR ARGO BED, ROUTT COUNTY, COLO.

Four ignition tests and three propagation tests were made of 20-mesh dust prepared from a 3-ton sample of run-of-mine coal obtained from a mine working the Pinnacle or Argo bed in Routt County, Colo. The dust was so prepared that 20 per cent would pass 200-mesh, as this was the standard size nearest to the size of the road and rib dusts found in the mine.

CONDITIONS IN MINE WHERE SAMPLE WAS OBTAINED

A standard explosion-hazard investigation of the mine was made. Four standard face samples of coal were taken, and analyses of these are shown in Table 10:

TABLE 10.—*Analyses of face samples of coal from a Colorado mine working the Pinnacle or Argo bed*

Laboratory No.	Coal as received				Moisture plus ash	Ratio, $\frac{V}{V+FC}$
	Moisture	Volatile matter	Fixed carbon	Ash		
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	
31130	8.5	39.1	49.2	3.2	11.7	44.2
31131	9.3	39.3	48.2	3.2	12.5	44.9
31132	8.0	39.0	46.6	6.4	14.4	45.6
31133	8.9	38.8	48.3	4.0	12.9	44.5

Analyses of a composite of these samples are as follows:

Analyses of composite samples

[Coal as received]

Proximate analysis:	Per cent	Ultimate analysis:	Per cent
Moisture	8.6	Hydrogen	5.8
Volatile matter	39.1	Carbon	69.4
Fixed carbon	48.0	Nitrogen	1.5
Ash	4.3	Oxygen	18.7
Moisture plus ash	12.9	Sulphur	.4
Ratio of volatile to total combustible	44.9	Ash	4.2

Eight standard samples of road dust and rib dust were collected. The results of the analyses and sizing tests of these samples are given in Table 11.

TABLE 11.—*Analyses and sizing tests of road dust and rib dust from a Colorado mine working the Pinnacle or Argo bed*

Laboratory No.	Kind of dust	Analysis as received				Moisture plus ash	Percentage of 20-mesh material through—	
		Moisture	Volatile matter	Fixed carbon	Ash		100-mesh screen	200-mesh screen
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*		
31117	Road dust	11.1	36.0	41.3	11.6	21.7	40.0	16.6
31118	do	8.5	33.6	39.1	18.8	27.3	37.6	21.0
31137	do	11.5	33.3	39.8	15.4	26.9	14.2	5.9
31138	do	7.2	24.2	21.1	47.5	54.7	45.1	34.6
31119	Rib dust	24.7	30.4	37.7	7.2	31.9	30.7	13.2
31120	do	9.4	33.4	36.4	20.8	30.2	66.7	56.1
31135	do	8.8	35.6	37.1	18.5	27.3	62.5	43.4
31136	do	15.4	12.6	7.9	64.1	79.5	31.6	15.0

These samples are variable in size and composition. On the basis of relative weights of the corresponding road and rib dust samples, the average content of 200-mesh dust is about 20 per cent, and in lieu of more detailed information this size was adopted for preparing the coal dust in the explosion tests.

Four samples of mine air were taken, two in the main return and two in still air near different faces. The main return showed 0.02 per cent methane, while the samples in still air showed 0.04 and 0.03 per cent, respectively. This mine was thus indicated to be practically free of fire damp at the time of the investigation.

DETAILS OF EXPLOSION TESTS

Procedure and results.—Four ignition tests were made without gas, two propagation tests were made without gas, and one propagation test was made with gas present. The average of the analyses of coal dust from the Pinnacle bed just before mixing for the tests was as follows:

Average analysis of 20-mesh coal dust from the Pinnacle or Argo bed

Constituents:	Per cent
Moisture	7.7
Volatile matter	39.2
Fixed carbon	48.7
Ash	4.4
Moisture plus ash	12.1
Ratio of volatile to total combustible	44.6

The average of the sizing tests of the coal dust was as follows: Through 20-mesh, 98 per cent; through 48-mesh, 60.8 per cent; through 100-mesh, 35.6 per cent; and through 200-mesh, 20 per cent. The results of the explosion tests are given in Table 12.

PROPAGATION TEST

The propagation-test method differs from the ignition-test meth only in the character of the dust distributed in the main entry fr the cannon to the last cut-through. In the propagation test 1 pounds of pure pulverized (85 per cent 200-mesh) Pittsburgh c dust is distributed on the side shelves, floor, and one cross shelf this 50-foot zone. The blown-out shot is fired into this pure c dust, which ignites and causes projection of a large volume of fla into the mixed dust under test. This mixed dust is distribu in the last cut-through and outby on both entries, as in the ignit test. If the mixed dust ignites and flame is carried to either e of the test zone, it is said that "propagation is obtained." If flame dies out before reaching both ends of the test zone it is s that "propagation is not obtained." It sometimes happens a propagation test that the flame will extend to one end of the t zone but not to the other. The practical interpretation of this that the mixture being tested lies very close to the dividing line explosibility and should be considered unsafe, as it gave propagat in one zone. When the mixture is definitely nonexplosive, the fla extension may vary from 100 to 300 feet, depending on how cl the mixture lies to the explosive limit.

The propagation test is more severe than the ignition test. T starting impulse of the fine coal dust is about the same as would obtained by the ignition of an explosive gas mixture confined the same volume.

ANALYSIS OF DUST USED

The Pittsburgh coal dust in the mixtures in the six ignition a propagation tests and the pulverized Pittsburgh coal dust used the ignition zones of propagation tests had the following aver proximate analyses, on an as-received basis:

Average proximate analyses of standard Pittsburgh coal dust

Constituent	Dust used in mixtures	Dust u in igni zone
	Per cent	*Per c*
Moisture	2.1	
Volatile matter	36.6	
Fixed carbon	55.4	
Ash	5.9	
Moisture plus ash	8.0	
Ratio of volatile to total combustible	39.8	

The shale dust used in the mixtures was the pit shale described page 150 of Bulletin 167 and contained an average of 1.7 per c moisture and 89.5 per cent ash. A proximate analysis does not sh the true composition of a shale or clay, because of the water of cc

Discussion of results.—Ignition was obtained in test 501 with pure 20-mesh coal dust from the Pinnacle bed; the explosion was of moderate violence. Ignition was not obtained in test 500 with a mixture containing 29.7 per cent incombustible material (20 per cent shale). Mixtures containing 38.5 and 47.3 per cent incombustible (30 and 40 per cent shale) had been tried earlier in tests 498 and 497, and ignition had not been obtained in either test. No gas was present in any of the ignition tests.

Complete propagation was not obtained in the absence of gas in test 496 with a mixture containing 56.1 per cent incombustible (50 per cent shale). The flame stopped 25 feet short of the end of the zone in the entry but traveled the entire distance in the air course. This mixture is on the border line, and must be considered as explosive. The safe mixture is given by test 499, in which propagation was not obtained with a mixture containing 64.8 per cent of incombustible (60 per cent shale) with no gas present. In test 502 the 40–60 coal-shale mixture was tried with 1.2 per cent gas in the air current, and propagation was obtained.

CONCLUSIONS ON EXPLOSIBILITY OF DUST FROM PINNACLE BED

The tests show that pure 20-mesh coal dust from the Pinnacle bed will ignite and propagate an explosion in the size found in the mine. The ratio of volatile to total combustible was 4.6 per cent higher than that of Pittsburgh dust, and the moisture content was about 6 per cent higher. As regards the propagation tests, the Pinnacle bed had nearly the same explosibility as Pittsburgh dust, but it was much harder to ignite—that is, it is less sensitive to a weak source of ignition than is Pittsburgh dust. Twenty per cent shale prevented ignition of dust from the Pinnacle bed, whereas 40 per cent was required for Pittsburgh dust. (See Table 20, p. 206, Bulletin 167.)

To prevent propagation of an explosion in a mine working the Pinnacle bed, the dust must have a total incombustible content of 65 per cent where there is no fire damp present.

It will be noted that the ratio of volatile to total combustible for dust from the Pinnacle bed was 0.4 per cent less than that for dust from the Wadge bed, yet it required 7 per cent more incombustible to prevent propagation of an explosion in dust from the Pinnacle bed than in dust from the Wadge bed. The variation of explosibility with composition of the coal is discussed later.

Application to field conditions.—The mine from which the samples came was practically free of methane at the time of the investigation, and under these conditions it is necessary to have 65 per cent incombustible in the dust to prevent propagation of an explosion. Only one of the road and rib dusts contained more than this amount;

the others ranged from 22 to 55 per cent incombustible. It would require somewhat more than an equal weight of rock dust to raise the incombustible content of all the road and rib dusts above the required amount. However, if methane is encountered in the future, it will be necessary to increase the amount of rock dust 5 to 10 per cent over the figures given in order to prevent propagation. The application of a heavy coating of rock dust to raise the incombustible content of the road and rib dusts above 80 per cent would be desirable and would produce safe conditions for a time, the length of which would depend upon the rate at which fresh coal dust accumulated.

EXPLOSIBILITY TESTS OF COAL DUST FROM RATON BED, COLFAX COUNTY, N. MEX. (A COKING COAL)

A series of four propagation tests and one ignition test was made of 20-mesh dust prepared from a 3,000-pound sample of run-of-mine coking coal from a mine working the Raton bed in Colfax County, N. Mex. The dust was so prepared that 20 per cent would pass 200-mesh. The size of the original dust in the mine could not be exactly determined, as the entries had been rock-dusted, but it was evident from the sizing tests of samples taken in the rock-dusted entries that the normal size of dust would approximate 20 per cent through 200-mesh.

CONDITIONS IN MINE WHERE SAMPLE WAS OBTAINED

Three standard face samples of coal were taken, the analysis being shown in Table 13.

TABLE 13.—*Analyses of face samples of coal from a New Mexico mine working the Raton bed*

Laboratory No.	Coal as received				Moisture plus ash	Ratio, $\frac{V}{V+FC}$
	Moisture	Volatile matter	Fixed carbon	Ash		
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	
98204	1.4	37.2	46.2	15.2	16.6	44.6
98203	2.1	37.9	47.2	12.8	14.9	44.6
98205	2.3	38.6	47.0	12.1	14.4	45.1

The analyses of a composite of these samples are as follows:

Analyses of composite sample

[Coal as received]

Proximate analysis:	Per cent	Ultimate analysis:	Per cent
Moisture	1.9	Hydrogen	5.4
Volatile matter	37.9	Carbon	70.8
Fixed carbon	46.1	Nitrogen	1.4
Ash	13.5	Oxygen	8.2
Moisture plus ash	15.4	Sulphur	.7
Ratio of volatile to total combustible	44.8	Ash	13.5

Twenty-three standard road-dust and rib-dust samples were collected. Table 14 shows the results of the analyses and sizing tests of these samples.

TABLE 14.—*Analyses and sizing tests of road dust and rib dust from a New Mexico mine working the Raton bed*

Laboratory No.	Kind of dust	Analysis as received				Moisture plus ash	Percentage of 20-mesh material through—	
		Moisture	Volatile matter	Fixed carbon	Ash		100-mesh screen	200-mesh screen
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*		
98168	Road dust	5.6	16.4	10.4	67.6	73.2	47.0	31.1
98169	do	6.3	22.8	22.6	48.3	54.6	28.5	27.6
98446	do	5.6	15.7	11.8	66.9	72.5	19.0	9.6
98170	do	5.6	29.5	32.6	32.3	37.9	27.2	13.6
98447	do	5.2	26.9	29.0	38.9	44.1	29.4	15.3
98171	do	6.1	11.9	7.5	74.5	80.6	16.8	16.6
98448	do	7.7	12.4	9.0	70.9	78.6	14.9	14.4
98449	do	6.4	14.5	13.6	65.5	71.9	20.2	9.8
98172	do	6.7	18.4	18.2	56.7	63.4	29.8	16.4
98450	do	6.3	14.3	12.7	66.7	73.0	19.6	18.3
98452	Rib dust	3.9	20.0	20.6	55.5	59.4	76.2	75.5
98183	Road dust	4.3	8.8	2.6	84.3	88.6	33.1	28.6
98184	do	4.4	9.7	3.9	82.0	86.4	57.2	31.1
98185	do	4.8	8.1	1.1	86.0	90.8	34.5	26.6
98186	do	8.3	8.0	1.8	81.9	90.2	26.8	10.2
98187	do	4.6	8.6	1.5	85.3	89.9	41.0	27.5
98188	do	4.3	7.3	1.6	86.8	91.1	46.4	22.3
98190	do	3.2	5.1	2.5	89.2	92.4	33.7	17.5
98189	do	5.5	10.6	7.8	76.1	81.6	28.4	25.4
98191	do	7.8	9.5	4.2	78.5	86.3	30.1	17.2
98192	do	5.3	8.4	5.2	81.1	86.4	31.8	15.9
98193	do	4.9	31.5	35.8	27.8	32.7	31.9	30.9
98194	do	11.5	30.2	38.0	20.3	31.8	21.5	10.8

Six samples of mine air were taken. The main return carried 0.05 per cent methane and at one face with only slight ventilation there was 0.13 per cent methane, the maximum found at any point. Small quantities of fire damp were given off, but the ventilation was good and with proper care of the dead ends accumulations probably would not form unless the fan was stopped for some reason. However, there is always a possibility of encountering gas blowers or of having gas liberated by falls of roof, so that due precautions are necessary, as shown by explosions in this coal field.

DETAILS OF EXPLOSION TESTS

Procedure and results.—Four propagation tests were made with mixtures of 20-mesh coal dust and shale dust—two without gas and two with gas. One ignition test was made with a mixture of coal dust and water. The average of the analyses of the Raton-bed coal dust just before mixing for the test was as follows:

Average of analyses of 20-mesh coal dust from the Raton bed

Constituents:	Per cent
Moisture	2.8
Volatile matter	37.8
Fixed carbon	46.9
Ash	12.5
Moisture plus ash	15.3
Ratio of volatile to total combustible	44.6

TABLE 15.—*Results of standard tests of 20-mesh, 20 per cent 200-mesh, coal dust from the Raton bed, Colfax County, N. Mex.*

PROPAGATION TESTS

Test No.	Date, 1924	Ratio of coal dust to shale dust in mixture	Mixed dust: Calculated incombustible content, per cent	Mixed dust: Rate of loading, pounds per foot	Mixed dust: Total loading, pounds	Natural gas used, per cent	Records obtained in entry or air course	Maximum pressure, pounds per square inch: Station 1150	Maximum pressure, pounds per square inch: Station 950	Time of tin-foil rupture at station E1250, second	Flame velocity between stations, feet per second: Station 1250 to station 1150	Flame velocity between stations, feet per second: Station 1150 to station 1050	Flame velocity between stations, feet per second: Station 1050 to station 950	Length of flame measured from cannon, feet	Remarks
622	Feb. 15	50:50	57.7	2.00	1,300	0.0	Entry	4	3	0.230	126	104	196	(1)	Propagation obtained.
							Air course	3	3				2 358	(1)	
636	Mar. 20	40:60	66.1	2.50	1,625	.0	Entry	1	1			32		200	Propagation not obtained.
							Air course	1	1			122		375	
623	Feb. 19	40:60	66.1	2.50	1,625	.9	Entry	5	3			275		(1)	Propagation obtained.
							Air course	3	3			218		(1)	
624	Feb. 25	30:70	74.5	3.33	2,167	1.0	Entry	1	1					150	Propagation not obtained.
							Air course	1	1					225	

IGNITION TEST

Test No.	Date, 1924	Ratio	Calculated incombustible content, per cent	Rate of loading, pounds per foot	Total loading, pounds	Natural gas used, per cent	Records obtained in entry or air course	Station 1150	Station 950	Time of tin-foil rupture	1250 to 1150	1150 to 1050	1050 to 950	Length of flame, feet	Remarks
635	Mar. 19	3 92:8	22.1	1.09	4 545	0.0	Entry	1	1					75	Ignition not obtained.
							Air course	1	1					100	

1 Flame extended through zone.
2 Velocity from station A 1150 to station A 950.
3 Pure 20-mesh coal dust and water mixed together in this test.
4 Dust loaded to E 1075 and A 1075 only.

The average of the sizing tests of the coal dust was as follows: Through 20-mesh, 98.7 per cent; through 48-mesh, 70.2 per cent; through 100-mesh, 38.1 per cent; and through 200-mesh, 20 per cent. The results of the explosion tests are shown in Table 15.

Discussion of results.—Propagation was obtained in test 622 with a mixture containing 57.7 per cent incombustible (50 per cent shale) but was not obtained in test 636 with a mixture containing 66.1 per cent incombustible (60 per cent shale); no gas was present in either test. The 40–60 coal-shale mixture was tried in test 623 with 0.9 per cent gas present, and propagation was obtained. Propagation was not obtained in test 624 with a mixture containing 74.5 per cent incombustible (70 per cent shale) with 1 per cent gas present.

In test 635 a mixture of 92 per cent pure coal dust and 8 per cent water (the total moisture content being 10 per cent) was tried and ignition was not obtained. The purpose of making this test was to determine the value of watering the dust at the face and of the use of sprays on the cutter bars of mining machines. The result was favorable to the method.

CONCLUSIONS ON EXPLOSIBILITY OF DUST FROM RATON BED

The tests show that an incombustible content of not less than 66 per cent was necessary in mixtures of 20-mesh coal dust from the Raton bed to prevent propagation of an explosion. With wet dust the moisture content had to be not less than 10.5 per cent to prevent direct ignition of the dust by a blown-out shot in the absence of gas. This dust is slightly more explosive than coal dust from the Pinnacle bed, which has the same ratio of volatile to total combustible but carries about 5 per cent more moisture. The dust from the Raton bed is also more explosive than Pittsburgh coal dust.

Application to field conditions.—At the mine from which the sample came careful attention was paid to the ventilation, and the percentage of methane in the entries was very low. Also rock dusting was being done in the entries up to a point near the face and the dust at the face was kept wet. If it be assumed that continued efficiency of the ventilating system would prevent any appreciable accumulation of fire damp the incombustible content of the road and rib dusts should be not less than 66 per cent. If it is desirable to make allowance for encountering some fire damp, this should be raised to 70 per cent.

Referring to Table 14 on road dusts and rib dusts collected, the incombustible content of 5 of the first 10 road dusts was above that required for no gas, and the content of the other 5 was below the required amount by 2.5 to 28 per cent. On the whole the section represented by these samples needed additional rock dust. The rib-dust sample was about 7 per cent below the required amount of incombustible material. Of the last 12 road-dust samples, 10 are 15 to 26 per cent above the limit and show excellent rock dusting; but one sample (98193) was taken at a point which had not been reached by the rock dusting and needed treatment, the other sample (98194) was from wet dust at the face and carried more than the amount of moisture required to prevent ignition. Evidently the rock-dusting system with watering at the face was being generally well executed, but needed attention at a few points to make the dust mixture of such composition that it would not propagate an explosion.

EXPLOSIBILITY TESTS OF COAL DUST FROM NO. 1 BED, SWEETWATER COUNTY, WYO.

Two ignition tests and two propagation tests were made of 20-mesh dust prepared from a 3,000-pound sample of run-of-mine coal obtained from a mine working No. 1 bed in Sweetwater County, Wyo. The dust was so prepared that 20 per cent would pass 200-mesh, as this was the standard size nearest that of the road dusts collected in the mine.

SAMPLES COLLECTED

No standard explosion-hazard investigation which would include mine-air sampling was made, as the purpose was to determine only the explosibility of the dust from this coal. Face samples and road-dust samples were collected, however, in order to determine the conditions under which the dust should be tested.

Two standard face samples were collected, and analyses are given in Table 16:

TABLE 16.—*Analyses of face samples of coal from a Wyoming mine working No. 1 bed*

Laboratory No.	Coal as received				Moisture plus ash	Ratio, $\frac{V}{V+FC}$
	Moisture	Volatile matter	Fixed carbon	Ash		
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	
99542	11.5	36.3	46.4	5.8	17.3	43.8
99543	11.2	36.5	46.3	6.0	17.2	44.1

The analyses of a composite of these samples are as follows:

Analyses of composite sample

[Coal as received]

Proximate analysis:	Per cent	Ultimate analysis:	Per cent
Moisture	11.4	Hydrogen	5.6
Volatile matter	36.2	Carbon	63.9
Fixed carbon	46.5	Nitrogen	1.4
Ash	5.9	Oxygen	22.4
Moisture plus ash	17.3	Sulphur	.8
Ratio of volatile to total combustible	43.8	Ash	5.9

Six samples of road dust and one sample of dust on timber were collected, and analyses and sizing tests of these are given in Table 17.

TABLE 17.—*Analyses and sizing tests of road dust and timber dust from a Wyoming mine working No. 1 bed*

Laboratory No.	Kind of dust	Analysis as received				Moisture plus ash	Percentage of 20-mesh material through—	
		Moisture	Volatile matter	Fixed carbon	Ash		100-mesh screen	200-mesh screen
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*		
99550	Road dust	9.1	35.2	36.0	19.7	28.8	45.1	24.2
99546	do	9.7	33.1	41.9	15.3	25.0	35.6	20.6
99545	do	16.0	30.7	37.2	16.1	32.1	24.1	11.3
99547	do	10.6	33.0	34.7	21.7	32.3	31.1	17.5
99548	do	12.8	31.6	32.0	23.6	36.4	23.9	12.5
99549	do	13.7	31.5	35.6	19.2	32.9	24.8	14.0
99551	Timber dust	7.3	33.3	36.8	22.6	29.9	91.6	87.0

The road dusts were rather coarse, and the one sample of timber dust was very fine. As no rib dusts were sampled, the average size of all dust can not be definitely predicted, but it would appear to be about 20 per cent through 200-mesh.

DETAILS OF EXPLOSION TESTS

Procedure and results.—Two ignition tests were made with 20-mesh dust—one with and one without gas. Two propagation tests were made with 20-mesh dust, one being with gas. The average of the analyses of the coal dust from No. 1 bed just before mixing for the tests was as follows:

Average of analyses of 20-mesh coal dust from No. 1 bed

Constituents:	Per cent
Moisture	10.9
Volatile matter	36.4
Fixed carbon	46.6
Ash	6.1
Moisture plus ash	17.0
Ratio of volatile to total combustible	43.8

The average of the sizing tests of the coal dust was as follows: Through 20-mesh, 98.3 per cent; through 48-mesh, 63.1 per cent; through 100-mesh, 35.5 per cent; and through 200-mesh, 20 per cent. The results of the explosion tests are given in Table 18.

TABLE 18.—*Results of standard tests of 20-mesh, 20 per cent 200-mesh, coal dust from No. 1 bed, Sweetwater County, Wyo.*

IGNITION TESTS

Test No.	Date, 1924	Ratio of coal dust to shale dust in mixture	Mixed dust			Natural gas used, per cent	Records obtained in entry or air course	Maximum pressure, pounds per square inch		Flame velocity between stations, feet per second		Length of flame measured from cannon, feet	Remarks
			Calculated incombustible content, per cent	Rate of loading, pounds per foot	Total loading, pounds			Station 1150	Station 950	Station 1150 to station 1050	Station 1050 to station 950		
638	Mar. 24	80:20	33.6	1.25	937.5	0.0	Entry	1	1			150	Ignition not obtained.
							Air course	1	1			225	
639	Mar. 25	60:40	50.2	1.66	1,250	1.8	Entry	11	8	292	383	(1)	Ignition obtained.
							Air course		9	299	800	(1)	

PROPAGATION TESTS

Test No.	Date, 1924	Ratio of coal dust to shale dust in mixture	Calculated incombustible content, per cent	Rate of loading, pounds per foot	Total loading, pounds	Natural gas used, per cent	Records obtained in entry or air course	Station 1150	Station 950	Station 1150 to station 1050	Station 1050 to station 950	Length of flame measured from cannon, feet	Remarks
637	Mar. 22	50:50	58.5	2.00	1,300	0.0	Entry	2	1	51		275	Propagation not obtained.
							Air course	2	2	89		375	
640	Mar. 26	30:70	75.1	3.33	2,167	1.9	Entry	4	3	181	72	(1)	Propagation obtained.
							Air course	2	1	209	255	(1)	

[1] Flame extended through zones.

Discussion of results.—Ignition was not obtained in test 638 with a mixture containing 33.6 per cent incombustible (20 per cent shale) with no gas present. With 1.8 per cent gas present, ignition was obtained in test 639 with a mixture containing 50.2 per cent incombustible (40 per cent shale). The explosion was fairly strong and rapid, and the incombustible content of such dust would have to be at least 60 per cent to prevent ignition in the presence of 2 per cent gas.

Propagation was not obtained in test 637 with a mixture containing 58.5 per cent incombustible material (50 per cent shale) and no gas present. The flame, however, extended within 25 feet of the end of the zone in the air course. This mixture lies very close to the border line of explosibility. Propagation was obtained in test 640 with a mixture containing 75.1 per cent incombustible (70 per cent shale) with 1.9 per cent gas present. This explosion was not very strong or rapid, and it is probable that a mixture containing 80 per cent incombustible would not propagate with 2 per cent gas present.

CONCLUSIONS ON EXPLOSIBILITY OF DUST FROM NO. 1 BED

The small quantity of coal furnished for these tests did not permit making enough tests to determine the limits of explosibility satisfactorily. However, assuming that the dust tested was representative of the size found in mines working No. 1 bed of Sweetwater County, the road and rib dusts would have to contain approximately 59 per cent incombustible to prevent the propagation of an explosion in the absence of gas. This coal dust appeared to be less explosive than Pittsburgh coal dust, judging from the few tests, despite the fact that its ratio of volatile to total combustible as tested was 3.8 per cent higher than that of Pittsburgh dust. However, gas may be encountered, as found at depth in other mines in southern Wyoming, and in order to be on the safe side it would be wise to maintain an incombustible content of 70 per cent.

EXPLOSIBILITY TESTS OF NO. 1 SAMPLE, ILLINOIS NO. 5 COAL, SALINE COUNTY

Separate samples were obtained from three different mines working the No. 5 bed in Saline County, Ill., and tests were made with each sample. These have been designated as No. 1, No. 2, and No. 3 samples, in the description of the tests.

Four ignition tests and six propagation tests were made of 20-mesh dust prepared from No. 1 sample, a 4-ton sample of run-of-mine coal. This dust was so prepared that 20 per cent would pass a 200-mesh screen, which is slightly finer than the average of the road and rib dusts collected in the mine. For purposes of comparison one additional propagation test was made with pulverized dust to obtain the maximum explosibility of the dust.

CONDITIONS IN MINE WHERE SAMPLE WAS OBTAINED

A standard explosion-hazard investigation of the mine was made. Three standard face samples of coal were taken, and the analyses are given in Table 19.

TABLE 19.—*Analyses of face samples of coal from a Saline County, Ill., mine working No. 5 bed*

Laboratory No.	Coal as received				Moisture plus ash	Ratio, $\frac{V}{V+FC}$
	Moisture	Volatile matter	Fixed carbon	Ash		
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	
33091	5.1	35.4	45.9	13.6	18.7	43.5
33092	5.8	37.2	47.3	9.7	15.5	44.0
33093	4.9	36.2	47.2	11.7	16.6	43.4

The analyses of a composite of these samples are as follows:

Analyses of composite sample

[Coal as received]

Proximate analysis:	Per cent	Ultimate analysis:	Per cent
Moisture	5.3	Hydrogen	4.9
Volatile matter	36.5	Carbon	66.4
Fixed carbon	46.7	Nitrogen	1.3
Ash	11.5	Oxygen	11.9
Moisture plus ash	16.8	Sulphur	4.0
Ratio of volatile to total combustible	43.9	Ash	11.5

Six road-dust and five rib-dust samples were collected. The results of the analyses and sizing tests of these samples are given in Table 20.

TABLE 20.—*Analyses and sizing tests of road dust and rib dust from a Saline County, Ill., mine working No. 5 bed*

Laboratory No.	Kind of dust	Analysis as received				Moisture plus ash	Percentage of 20-mesh material through—	
		Moisture	Volatile matter	Fixed carbon	Ash		100-mesh screen	200-mesh screen
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*		
33096	Road dust	9.8	25.4	30.2	34.6	44.4	12.7	5.5
33095	do	10.9	27.0	32.8	29.3	40.2	22.5	9.9
33097	do	3.3	15.5	16.3	64.9	68.2	39.1	24.8
34062	do	8.0	25.3	30.3	36.4	44.4	32.4	19.0
34061	do	9.0	25.2	22.9	42.9	51.9	28.4	16.0
34060	do	9.4	26.9	32.2	31.5	40.9	28.5	15.3
33100	Rib dust	7.3	21.2	18.7	52.8	60.1	38.5	29.6
33098	do	7.0	28.4	37.1	27.5	34.5	77.0	65.6
33099	do	2.0	7.5	5.8	84.7	86.7	27.1	19.2
34064	do	4.1	22.9	25.3	47.7	51.8	48.7	35.8
34065	do	11.1	30.3	19.5	39.1	50.2	28.4	16.6

Consideration of the relative weights of the road and rib dust obtained showed that the average content of moisture plus ash of all samples was 49.8 per cent, and the average content of 200-mesh dust was 18.4p er cent.

Samples of mine air were collected at three different points in the return, and the maximum amount of methane found was 0.36 per cent. Computations from the air volume showed that 150,000 cubic feet of methane was being liberated in the mine every 24 hours. It was being removed by adequate ventilation, but if ventilation should be interrupted or not carried to the face accumulations would certainly form.

DETAILS OF EXPLOSION TESTS

Procedure and results.—Four ignition tests were made with 20-mesh dust, two without gas and two with gas in the air current. Six propagation tests were made with 20-mesh dust, three being without gas and three with gas present. One propagation test was made with pulverized dust without gas. The average of the analyses of the 20-mesh and pulverized coal dust from No. 5 bed just before mixing for the tests was as follows:

Average of analyses of 20-mesh and pulverized coal dust from No. 5 bed

Constituents	20-mesh dust	Pulverized dust
	Per cent	*Per cent*
Moisture	4.2	4.0
Volatile matter	37.2	34.9
Fixed carbon	47.9	50.1
Ash	10.7	11.0
Moisture plus ash	14.9	15.0
Ratio of volatile to total combustible	43.7	41.1

In comparing these analyses it would appear that some of the volatile combustible matter in the coal was driven off in pulverizing, because the ratio of volatile to total combustible is less in the pulverized than in the 20-mesh dust.

The average of the sizing tests of the 20-mesh coal dust was as follows: Through 20-mesh, 98.3 per cent; through 48-mesh, 65.8 per cent; through 100-mesh, 35.3 per cent; and through 200-mesh, 20 per cent. Of the pulverized dust 99.6 per cent passed 100-mesh and 91.4 per cent passed 200-mesh. The results of the explosion tests are given in Table 21.

TABLE 21.—*Results of standard tests of coal dust from No. 5 bed, Saline County, Ill. No. 1 sample*

IGNITION TESTS WITH 20-MESH, 20 PER CENT 200-MESH, DUST

Test No.	Date, 1919–20	Ratio of coal dust to shale dust in mixture	Mixed dust: Calculated incombustible content, per cent	Mixed dust: Rate of loading, pounds per foot	Mixed dust: Total loading, pounds	Natural gas used, per cent	Records obtained in entry or air course	Maximum pressure, pounds per square inch: Station 1150	Maximum pressure, pounds per square inch: Station 950	Time of tin-foil rupture at station E 1250, second	Flame velocity between stations, feet per second: Station 1250 to station 1150	Flame velocity: Station 1150 to station 1050	Flame velocity: Station 1050 to station 950	Length of flame measured from cannon, feet	Remarks
560	Feb. 23	80:20	32.0	1.25	937.5	0.0	Entry	9	10	0.704	92	781	369	[1]	Ignition obtained.
							Air course	8	7			263	445	[1]	
537	Dec. 26	70:30	40.5	1.43	1,071	.0	Entry	1						125	Ignition not obtained.
							Air course	1	1					225	
539	Jan. 2	60:40	49.0	1.66	1,250	1.4	Entry	14	18	.700	107	752	1,053	[1]	Ignition obtained.
							Air course	17	20			625	1,087	[1]	
540	Jan. 5	50:50	57.5	2.00	1,500	1.0	Entry	1	1	.333				75	Ignition not obtained.
							Air course	1	1					125	

PROPAGATION TESTS WITH 20-MESH, 20 PER CENT 200-MESH, DUST

Test No.	Date, 1919–20	Ratio of coal dust to shale dust in mixture	Calculated incombustible content, per cent	Rate of loading, pounds per foot	Total loading, pounds	Natural gas used, per cent	Records obtained in entry or air course	Max. pressure Station 1150	Max. pressure Station 950	Time of tin-foil rupture at station E 1250, second	Station 1250 to station 1150	Station 1150 to station 1050	Station 1050 to station 950	Length of flame measured from cannon, feet	Remarks
541	Jan. 8	50:50	57.5	2.00	1,300	0.0	Entry	1	1	0.243	38			150	Propagation not obtained.
							Air course	1	1					175	
545	Jan. 14	50:50	57.5	2.00	1,300	.0	Entry	3	3	.306	169	111	118	[1]	Propagation obtained.
							Air course	3	3			165	242	[1]	
538	Dec. 29	40:60	66.0	2.50	1,625	.0	Entry	1	1	.424	51			125	Propagation not obtained.
							Air course	1	1					275	
544	Jan. 12	40:60	66.0	2.50	1,625	.9	Entry	4	5	.230		[2] 154	241	[1]	Propagation obtained.
							Air course	5	4			173	337	[1]	
557	Feb. 16	30:70	74.5	3.33	2,167	1.1	Entry	1	1	.240	63	38		200	Propagation not obtained.
							Air course	2	2			98		325	
559	Feb. 20	25:75	78.3	4.00	2,600	2.1	Entry	3	3	.200	125	52		275	Complete propagation not obtained.
							Air course	2	2			111	92	[1]	

PROPAGATION TEST WITH PULVERIZED, 91 PER CENT 200-MESH, DUST

Test No.	Date, 1919–20	Ratio of coal dust to shale dust in mixture	Calculated incombustible content, per cent	Rate of loading, pounds per foot	Total loading, pounds	Natural gas used, per cent	Records obtained in entry or air course	Max. pressure Station 1150	Max. pressure Station 950	Time of tin-foil rupture at station E 1250, second	Station 1250 to station 1150	Station 1150 to station 1050	Station 1050 to station 950	Length of flame measured from cannon, feet	Remarks
558	Feb. 18	30:70	74.5	3.33	2,167	0.0	Entry	6	7	0.295	236	156	196	[1]	Propagation obtained.
							Air course	6	8			257	341	[1]	

[1] Flame extended through zones.

[2] Velocity from station E 1250 to station E 1050.

Discussion of ignition tests.—Twenty-mesh dust was used for all the ignition tests. Ignition was obtained in test 560 with a mixture containing 32 per cent incombustible (20 per cent shale), but was not obtained in test 537 with a mixture containing 40.5 per cent incombustible (30 per cent shale); no gas was present in either test. Ignition was obtained in test 539 with a mixture containing 49 per cent incombustible (40 per cent shale) with 1.4 per cent gas in the air current. This explosion was very strong and rapid, and this mixture would not be safe with 1 per cent gas present. Ignition was not obtained in test 540 with a mixture containing 57.5 per cent incombustible (50 per cent shale) and 1 per cent gas present.

Discussion of propagation tests.—Six propagation tests were made with 20-mesh dust. Propagation was not obtained in test 541 with a mixture containing 57.5 per cent incombustible (50 per cent shale), with no gas present. This result was questioned, and in a check test (No. 545) propagation was obtained. This mixture was close to the border line of explosibility, which is not sharply defined, and must be considered unsafe in the mine. Propagation was not obtained in test 538 with a mixture containing 66 per cent incombustible material (60 per cent shale), with no gas present. This 40–60 coal-shale mixture was tried again in test 544 with 0.9 per cent gas present, and propagation was obtained. Propagation was not obtained in test 557 with a mixture containing 74.5 per cent incombustible (70 per cent shale), with 1.1 per cent gas present. In test 559 a mixture containing 78.3 per cent incombustible was tried with 2.1 per cent gas. The explosion traveled all the way through the zone in the air course but stopped 75 feet short in the entry. A mixture containing 80 per cent incombustible would probably be safe with 2 per cent gas present.

One propagation test (558) was made with pulverized dust without gas. The mixture contained 74.5 per cent incombustible (70 per cent shale). Propagation was obtained in this test.

103804°—27——6

CONCLUSIONS ON EXPLOSIBILITY OF DUST FROM NO. 5 BED FROM TESTS OF NO. 1 SAMPLE

The tests show that the dust from No. 5 bed coal in Saline County, Ill., is explosive. The amount of incombustible necessary to prevent ignition or propagation in mixtures of 20-mesh dust, 20 per cent of which will pass 200-mesh, is as follows:

Incombustible material needed to prevent ignition or propagation in coal dust from No. 5 bed

Condition	Gas used	Incombustible in mixture	Rock dust in mixture
	Per cent	*Per cent*	*Per cent*
Nonignition	0	41	30
Do	1	56	50
Nonpropagation	0	66	60
Do	1	75	70
Do	2	80	77

The propagation limits for dust from Illinois No. 5 coal are much the same as for the Pittsburgh dust, which carries between 2 and 3 per cent less moisture and has a ratio of volatile to total combustible 3.7 per cent less than the 20-mesh No. 5 coal dust as tested, but it is less sensitive to ignition than Pittsburgh dust.

Application to field conditions.—As the mine from which the coal came was making considerable gas, it would be better to use enough rock dust to make the dust safe in the presence of 1 per cent gas, and this would require a total incombustible content of 75 per cent to prevent propagation of an explosion. Only one of the road-dust and rib-dust samples contained more than this quantity of moisture plus ash; the others ranged from 35 to 68 per cent. It would be necessary to add 1 to 1.6 pounds of rock dust to a pound of these dusts to render them nonexplosive. A thorough rock dusting would bring the incombustible content of the dust above the amount required. The time when another application of rock dust would be needed would depend on the rate at which fresh coal dust accumulated.

EXPLOSIBILITY TESTS OF NO. 2 SAMPLE, ILLINOIS NO. 5 COAL, SALINE COUNTY

Explosibility tests were made of the second of three separate samples obtained from three different mines working the No. 5 bed in Saline County, Ill. Seven ignition tests and three propagation tests were made of 20-mesh dust so prepared from this sample that 20 per cent would pass a 200-mesh sieve, which is about 2 per cent coarser than the average of the road and rib dusts collected. Two additional ignition tests were made with pulverized dust to find the maximum explosibility of the coal for comparative purposes.

CONDITIONS IN MINE WHERE NO. 2 SAMPLE WAS OBTAINED

A standard explosion-hazard investigation was made of the mine. Three standard face samples of coal were taken, and analyses of these are given in Table 22.

TABLE 22.—*Analyses of face samples from second mine sampled in Saline County, Ill., working No. 5 bed*

Laboratory No.	Coal as received				Moisture plus ash	Ratio, $\frac{V}{V+FC}$
	Moisture	Volatile matter	Fixed carbon	Ash		
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	
33081	5.6	36.1	48.1	10.2	15.8	42.9
33082	6.1	35.8	50.0	8.1	14.2	41.7
33083	6.7	32.6	50.6	10.1	16.8	39.2

The analyses of a composite of these samples are as follows:

Analyses of composite sample

[Coal as received]

Proximate analysis:	Per cent	Ultimate analysis:	Per cent
Moisture	6.2	Hydrogen	5.2
Volatile matter	34.5	Carbon	68.8
Fixed carbon	49.9	Nitrogen	1.6
Ash	9.4	Oxygen	11.5
Moisture plus ash	15.6	Sulphur	3.5
Ratio of volatile to total combustible	40.9	Ash	9.4

Seven road-dust and seven rib-dust samples were collected. The results of the analyses and sizing tests of these samples are given in Table 23.

TABLE 23.—*Analyses and sizing tests of road dust and rib dust from second mine sampled in Saline County, Ill., working No. 5 bed*

Laboratory No.	Kind of dust	Analysis as received				Moisture plus ash	Percentage of 20-mesh material through—	
		Moisture	Volatile matter	Fixed carbon	Ash		100-mesh screen	200-mesh screen
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*		
33087	Road dust	4.9	29.1	41.2	24.8	29.7	44.4	31.4
33085	do	10.4	18.9	19.2	51.5	61.9	32.0	15.4
33086	do	8.1	24.0	32.0	35.9	44.0	36.7	21.0
34053	do	12.4	24.8	34.3	28.5	40.9	25.1	12.7
34054	do	10.3	26.4	28.9	34.4	44.7	38.3	21.1
34055	do	9.7	25.0	29.2	36.1	45.8	41.0	26.9
34052	do	9.1	21.0	26.6	43.3	52.4	37.0	23.1
33090	Rib dust	4.4	17.0	18.9	59.7	64.1	51.9	41.8
33089	do	9.3	29.1	31.5	30.1	39.4	35.7	21.8
33088	do	12.3	28.6	44.2	14.9	27.2	6.0	2.3
34058	do	13.1	27.1	40.5	19.3	32.4	36.3	13.3
34059	do	11.9	28.1	22.7	37.3	49.2	55.9	45.1
34056	do	12.6	29.0	20.0	38.4	51.0	48.6	29.2
34057	do	14.4	27.7	25.3	32.6	47.0	36.7	17.9

Consideration of the relative weights of the road and rib dusts obtained showed that the average content of moisture and ash for all samples was 45.5 per cent, and the average content of 200-mesh dust was 22.1 per cent.

Samples of mine air were collected at three places in the return, and showed a maximum of 0.50 per cent methane. The total amount of methane liberated in 24 hours was computed from the analyses and air measurements, and was found to be 160,000 cubic feet. Thus, methane was being liberated in large quantities at the time of the investigation, but was being diluted by the ventilating current to 0.5 per cent or less. Accumulations would certainly occur if ventilation was interrupted or air was not properly carried to the working faces.

DETAILS OF EXPLOSION TESTS

Procedure and results.—Seven ignition tests were made with 20-mesh dust, two being without gas and five with gas present. Three propagation tests were made with 20-mesh dust, gas being used in only one of them. Two ignition tests were made with pulverized dust to determine the maximum explosibility of the coal in the presence and in the absence of gas. The average of the analyses of 20-mesh and pulverized coal dust from No. 5 bed just before mixing for the tests was as follows:

Average of analyses of 20-mesh and pulverized coal dust from No. 5 bed

Constituents	20-mesh dust	Pulverized dust
	Per cent	*Per cent*
Moisture	4.9	4.4
Volatile matter	34.9	32.8
Fixed carbon	50.8	53.4
Ash	9.4	9.4
Moisture plus ash	14.3	13.8
Ratio of volatile to total combustible	40.7	38.0

Comparison of these analyses seems to indicate that the coal lost some of its volatile matter in pulverizing, as the ratio of volatile to total combustible is lower in the finer dust. This was also observed in the dust prepared from No. 1 sample from No. 5 bed, already reported.

The average of the sizing tests of the 20-mesh coal dust was as follows: Through 20-mesh, 97.2 per cent; through 48-mesh, 69.5 per cent; through 100-mesh, 37.5 per cent; and through 200-mesh, 20 per cent. Of the pulverized dust, 99.8 per cent passed 100-mesh and 92.6 per cent passed 200-mesh. The results of the explosion tests are given in Table 24.

TABLE 24.—*Results of standard tests of coal dust from No. 5 bed, Saline County, Ill. No. 2 sample*

Test No.	Date, 1919–20	Ratio of coal dust to shale dust in mixture	Mixed dust: Calculated incombustible content, per cent	Mixed dust: Rate of loading, pounds per foot	Mixed dust: Total loading, pounds	Natural gas used, per cent	Records obtained in entry or air course	Maximum pressure, pounds per square inch: Station 1150	Maximum pressure, pounds per square inch: Station 950	Time of tin-foil rupture at station E1250, seconds	Flame velocity between stations, feet per second: Station 1250 to station 1150	Flame velocity between stations, feet per second: Station 1150 to station 1050	Flame velocity between stations, feet per second: Station 1050 to station 950	Length of flame measured from cannon, feet	Remarks
							IGNITION TESTS WITH 20-MESH, 20 PER CENT 200-MESH, DUST								
521	Nov. 17	80:20	31.4	1.25	937.5	0.0	Entry	8	15	1.000		[1] 170	595	(2)	Ignition obtained.
							Air course	7	9			254	862	(2)	
561	Feb. 24	70:30	40.0	1.43	1,072	.0	Entry	1	1	.428				75	Ignition not obtained.
							Air course	½	½					125	
562	...do.....	(3)	(3)	(3)	(3)	1.3	Entry	1	1					50	Do.
							Air course	1	½					75	
563	Feb. 25	70:30	40.0	1.43	1,072	1.3	Entry	20	19	.423	97	481	1,408	(2)	Ignition obtained.
							Air course	14	19			312	719	(2)	
530	Dec. 8	60:40	48.6	1.67	1,250	.7	Entry	1	1	.667				75	Ignition not obtained.
							Air course	½	½					100	
527	Dec. 1	60:40	48.6	1.67	1,250	1.5	Entry	4	7	.428	61	139	375	(2)	Ignition obtained.
							Air course	4	4			251	474	(2)	
569	Mar. 10	50:50	57.2	2.00	1,500	2.1	Entry	5	6	.707	80	148	437	(2)	Do.
							Air course	5	6			160	440	(2)	
							PROPAGATION TESTS WITH 20-MESH, 20 PER CENT 200-MESH, DUST								
526	Nov. 28	50:50	57.2	2.00	1,300	0.0	Entry	5	4	0.222	153	162		(2)	Propagation obtained.
							Air course	4	5			287	704	(2)	
528	Dec. 4	40:60	65.7	2.50	1,625	.0	Entry	½	½	.317	112			150	Propagation not obtained.
							Air course	½	½					250	
531	Dec. 10	40:60	65.7	2.50	1,625	1.2	Entry	6	5	.306		[1] 170	274	(2)	Propagation obtained.
							Air course	5	5				419	(2)	
							IGNITION TESTS WITH PULVERIZED, 93 PER CENT 200-MESH, DUST								
571	Mar. 15	40:60	65.5	2.50	1,875	0.0	Entry	1	1	1.667				150	Ignition not obtained.
							Air course	1	1					150	
572	...do.....	40:60	65.5	2.50	1,875	1.2	Entry	15	15	2.542	243	315	1,695	(2)	Ignition obtained.
							Air course	10	13			298	617	(2)	

[1] Velocity from station E 1250 to station E 1050.
[2] Flame extended through zones.
[3] Residue of test 561 used in this test.

Discussion of ignition tests.—Seven ignition tests were made with 20-mesh dust. Ignition was obtained in test 521 with a mixture containing 31.4 per cent incombustible (20 per cent shale), with no gas in the air. Ignition was not obtained in test 561 with a mixture containing 40 per cent incombustible (30 per cent shale), with no gas present. Immediately after test 561, 1.3 per cent of gas was run into the air current and the shot was fired again (test 562). The flame was shorter in this test than with no gas present; the explanation is that the dust near the cannon had been heavily coked by the powder flame in test 561 and had lost part of its volatile matter, which probably reduced its explosibility. A fresh 70–30 coal-shale mixture was prepared for test 563 and was tried with 1.3 per cent gas in the air current. A strong, rapid explosion resulted, proving the error in the results of test 562. Ignition was not obtained in test 530 with a mixture containing 48.6 per cent incombustible (40 per cent shale) and with 0.7 per cent gas present, but was obtained in test 527 with a similar mixture and 1.5 per cent gas present. It is doubtful whether this mixture would be safe with 1 per cent gas present; it would be better to use 52 per cent incombustible. Ignition was obtained in test 569 with a mixture containing 57.2 per cent incombustible (50 per cent shale), with 2.1 per cent gas in the air current.

Two ignition tests were made with pulverized dust which averaged 92.6 per cent through 200-mesh. Ignition was not obtained in test 571 with a mixture containing 65.5 per cent incombustible (60 per cent shale), with no gas present, but a strong rapid explosion was obtained in test 572 with this mixture and 1.2 per cent gas present.

Discussion of propagation tests.—Propagation was obtained in test 526 with a mixture containing 57.2 per cent incombustible material (50 per cent shale), but was not obtained in test 528 with a mixture containing 65.7 per cent incombustible material (60 per cent shale), without gas in either test. Propagation was obtained in test 531 with a mixture containing 65.7 per cent incombustible material (60 per cent shale) in the presence of 1.2 per cent gas.

CONCLUSIONS ON EXPLOSIBILITY OF DUST FROM NO. 5 BED FROM TESTS OF NO. 2 SAMPLE

The test shows that dust from Illinois No. 5 coal is explosive. The limits determined are nearly the same as those determined for No. 1 sample from the same bed and are also much the same as those for Pittsburgh coal dust. The percentages of incombustible necessary to prevent ignition or propagation of 20-mesh dust, 20 per cent of which will pass 200-mesh, under various conditions are as follows:

Incombustible material needed to prevent ignition or propagation in coal dust from No. 5 bed

Condition	Gas used	Incombustible in mixture	Rock dust in mixture
	Per cent	*Per cent*	*Per cent*
Nonignition	0	40	30
Do	1	52	45
Nonpropagation	0	66	60

Application to field conditions.—As the mine sampled was making considerable fire damp it would be advisable to use enough rock dust to make the dust safe in the presence of 1 per cent gas. A mixture that would not propagate an explosion in the presence of 1 per cent gas was not determined in the series of tests of this coal sample, but was determined in the series on No. 1 sample from the same bed, as already reported. It was found that an incombustible content of 75 per cent is required to prevent propagation in the presence of 1 per cent gas, and this amount can be taken as suitable for the mine where No. 2 sample was obtained, as the observed limits of explosibility for Nos. 1 and 2 samples were nearly the same, where these were determined.

None of the 14 samples of road and rib dust collected contained this amount of incombustible material; the highest content found was 64 per cent, and it would be necessary to add up to 2 parts of rock dust to the various samples to render them inert. Thorough rock dusting would bring the incombustible content above the amount required and would produce safe conditions for a time, the length of which would depend on the rate at which fresh coal dust accumulated.

EXPLOSIBILITY TESTS OF NO. 3 SAMPLE, ILLINOIS NO. 5 COAL, SALINE COUNTY, ILL.

Six ignition tests and six propagation tests were made of 20-mesh coal dust prepared from No. 3 sample, which was a 4-ton sample from the third mine working the No. 5 bed in Saline County, Ill. The dust was so prepared that 20 per cent would pass 200-mesh, which was the average size of the road and rib dusts collected in the mine. One propagation test was made with pulverized dust in order to obtain the maximum explosibility of the dust for purposes of comparison.

CONDITIONS IN MINE WHERE NO. 3 SAMPLE WAS OBTAINED

A standard explosion-hazard investigation was made of the mine. Three face samples were taken, analyses of which are given in Table 25.

TABLE 25.—*Analyses of face samples of coal from third mine sampled in Saline County, Ill., working No. 5 bed*

Laboratory No.	Coal as received				Moisture plus ash	Ratio, $\frac{V}{V+FC}$
	Moisture	Volatile matter	Fixed carbon	Ash		
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	
33101	7.5	33.9	49.9	8.7	16.2	40.5
33102	7.9	33.8	50.2	8.1	16.0	40.2
33103	8.3	33.3	49.6	8.8	17.1	40.2

The analyses of a composite of these samples are as follows:

Results of analyses of composite sample

[Coal as received]

Proximate analysis:	Per cent	Ultimate analysis:	Per cent
Moisture	7.9	Hydrogen	5.3
Volatile matter	33.2	Carbon	68.2
Fixed carbon	50.4	Nitrogen	1.6
Ash	8.5	Oxygen	13.9
Moisture plus ash	16.4	Sulphur	2.5
Ratio of volatile to total combustible	39.7	Ash	8.5

Seven road-dust and seven rib-dust samples were collected. The results of the analyses and sizing tests of these samples are given in Table 26.

TABLE 26.—*Analyses and sizing tests of road dust and rib dust from third Illinois mine working No. 5 bed*

Laboratory No.	Kind of dust	Analysis as received				Moisture plus ash	Percentage of 20-mesh material through—	
		Moisture	Volatile matter	Fixed carbon	Ash		100-mesh screen	200-mesh screen
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*		
33106	Road dust	8.0	24.5	40.4	27.1	35.1	41.3	28.2
33105	do	8.0	29.9	49.5	12.6	20.6	40.3	24.5
33107	do	5.8	18.3	26.6	49.3	55.1	32.3	20.9
33517	do	7.4	25.7	45.4	21.5	28.9	36.1	22.6
33516	do	7.5	20.5	29.4	42.6	50.1	32.4	20.7
33514	do	6.6	22.4	26.6	44.4	51.0	35.0	22.5
33513	do	13.1	17.7	21.4	47.8	60.9	19.2	8.0
33109	Rib dust	7.5	22.2	37.3	33.0	40.5	38.7	27.4
33110	do	14.7	29.5	33.3	22.5	37.2	6.6	2.5
33108	do	8.9	26.7	39.9	24.5	33.4	33.5	20.7
33518	do	13.2	20.9	27.0	38.9	52.1	20.0	9.9
33519	do	10.9	28.5	36.2	24.4	35.3	38.0	22.8
33515	do	14.5	28.5	28.2	28.8	43.3	32.6	16.7
33512	do	15.2	26.8	32.5	25.5	40.7	19.9	7.1

Consideration of the relative weights of the road and rib dusts obtained showed that the average content of moisture and ash for all the samples was 42.6 per cent, and the average content of 200-mesh dust was 20.1 per cent.

Samples of mine air were collected at two places in the return and showed a maximum of 0.86 per cent methane. The total amount of methane liberated in 24 hours was computed to be 160,000 cubic feet. Therefore, this mine was liberating large quantities of fire damp at the time of the investigation, and the percentage in the return was much higher than it should be, showing that not enough air was being circulated through the workings. Accumulations of gas would certainly form if the fan was stopped. With the fan running, 1 or 2 per cent of gas probably would often be found at the face when there was more than 0.75 per cent in the main return. The conditions of ventilation and gas may be explained by the fact that this mine had not been long in operation, and the permanent fan which was to be installed would have a much larger capacity than the one then being used.

DETAILS OF EXPLOSION TESTS

Procedure and results.—Six ignition tests were made with 20-mesh dust, two without gas and four with gas in the air current. Six propagation tests were made with 20-mesh dust, two being without gas and four with gas present. One propagation test was made with pulverized dust in the absence of gas to determine the maximum explosibility of the coal. The average of the analyses of the 20-mesh and pulverized coal dust from No. 5 bed just before mixing for the tests was as follows:

Average of analyses of 20-mesh and pulverized coal dust from No. 5 bed

Constituents	20-mesh dust	Pulverized dust
	Per cent	*Per cent*
Moisture	6.7	6.1
Volatile matter	33.2	32.5
Fixed carbon	51.9	53.5
Ash	8.2	7.9
Moisture plus ash	14.9	14.0
Ratio of volatile to total combustible	39.0	37.8

The analyses of pulverized dust showed a lower ratio of volatile to total combustible content, as did the similar analyses for No. 1 and No. 2 samples.

The average of the sizing tests of the coal dust was as follows: Through 20-mesh, 96.3 per cent; through 48-mesh, 67.7 per cent; through 100-mesh, 35.9 per cent; and through 200-mesh, 20 per cent. Of the pulverized dust 99.6 per cent passed 100-mesh and 92.4 per cent passed 200-mesh. The results of the explosion tests are given in Table 27.

TABLE 27.—*Results of standard tests of coal dust from No. 5 bed, Saline County, Ill. No. 3 sample*

IGNITION TESTS WITH 20-MESH, 20 PER CENT 200-MESH, DUST

Test No.	Date, 1919–20	Ratio of coal dust to shale dust in mixture	Mixed dust: Calculated incombustible content, per cent	Mixed dust: Rate of loading, pounds per foot	Mixed dust: Total loading, pounds	Natural gas used, per cent	Records obtained in entry or air course	Maximum pressure, pounds per square inch: Station 1150	Maximum pressure, pounds per square inch: Station 950	Time of tin-foil rupture at station E1250, seconds	Flame velocity between stations, feet per second: Station 1250 to station 1150	Flame velocity between stations, feet per second: Station 1150 to station 1050	Flame velocity between stations, feet per second: Station 1050 to station 950	Length of flame measured from cannon, feet	Remarks
525	Nov. 24	80:20	32.0	1.25	937.5	0.0	Entry	8	12	0.803	115	174	1,563	(1)	Ignition obtained.
							Air course	7	9			281	518	(1)	
522	Nov. 20	70:30	40.5	1.43	1,071	.0	Entry		2	3.626				75	Ignition not obtained.
							Air course	1	1					125	
532	Dec. 12	70:30	40.5	1.43	1,071	.9	Entry	5	6	.745	71	173	231	(1)	Ignition obtained.
							Air course	5	6			216	400	(1)	
565	Mar. 3	60:40	49.0	1.50	1,250	1.2	Entry	1	1	.714	31			100	Ignition not obtained.
							Air course	1	1					225	
534	Dec. 17	50:50	57.5	2.00	1,500	2.1	Entry	3	13	.703	119	263	935	(1)	Ignition obtained.
							Air course	5	12			287	675	(1)	
566	Mar. 5	40:60	66.0	2.50	1,875	2.3	Entry	1	1	1.215				75	Ignition not obtained.
							Air course	1	1					125	

PROPAGATION TESTS WITH 20-MESH, 20 PER CENT 200-MESH, DUST

Test No.	Date, 1919–20	Ratio of coal dust to shale dust in mixture	Mixed dust: Calculated incombustible content, per cent	Mixed dust: Rate of loading, pounds per foot	Mixed dust: Total loading, pounds	Natural gas used, per cent	Records obtained in entry or air course	Maximum pressure, pounds per square inch: Station 1150	Maximum pressure, pounds per square inch: Station 950	Time of tin-foil rupture at station E1250, seconds	Flame velocity between stations, feet per second: Station 1250 to station 1150	Flame velocity between stations, feet per second: Station 1150 to station 1050	Flame velocity between stations, feet per second: Station 1050 to station 950	Length of flame measured from cannon, feet	Remarks
564	Feb. 26	50:50	57.5	2.00	1,300	0.0	Entry	5	6	0.277	224	180	129	(1)	Propagation obtained.
							Air course	6	6			247	625	(1)	
535	Dec. 19	40:60	66.0	2.50	1,625	.0	Entry	1	1	.438	42			125	Propagation not obtained.
							Air course	2	1					250	
567	Mar. 5	40:60	66.0	2.50	1,625	.8	Entry	2	3	.222	113	127	62	325	Complete propagation not obtained.
							Air course	3	4			139	493	(1)	
533	Dec. 15	30:70	74.5	3.33	2,167	.8	Entry	1	1					125	Propagation not obtained.
							Air course	2	1					250	
536	Dec. 22	25:75	78.8	4.00	2,600	1.6	Entry	1	1	.243	110	83		175	Do.
							Air course	1	1			106		375	
568	Mar. 8	25:75	78.8	4.00	2,600	2.4	Entry	2	2	.236	132	59		275	Complete propagation not obtained.
							Air course	2	2			111	102	(1)	

PROPAGATION TEST WITH PULVERIZED, 92 PER CENT 200-MESH, DUST

570	Mar. 12	25:75	78.8	4.00	2,600	0.0	Entry	1	0	0.303	28	--------	--------	125	Propagation not obtained.
							Air course	1	0	--------	--------	--------	--------	175	

[1] Flame extended through zones.

Discussion of ignition tests.—Twenty-mesh dust was used for all ignition tests. Ignition was obtained in test 525 with a mixture containing 32 per cent incombustible material (20 per cent shale), but was not obtained in test 522 with a mixture containing 40.5 per cent incombustible (30 per cent shale); no gas was present in either test. The 70–30 coal-shale mixture was tried again in test 532 with 0.9 per cent gas present, and ignition was obtained. Ignition was not obtained in test 565 with a mixture containing 49 per cent incombustible (40 per cent shale) with 1.2 per cent gas in the air current. The flame extension was rather long in this test, and it would be preferable to set 51 per cent incombustible as the safe limit for prevention of ignition with 1 per cent gas present. In test 534 a mixture containing 57.5 per cent incombustible (50 per cent shale) was tried with 2.1 per cent gas, and ignition was obtained. In test 566 the incombustible content of the mixture was raised to 66 per cent (60 per cent shale), and ignition was not obtained with 2.3 per cent gas present.

Discussion of propagation tests.—Six propagation tests were made with 20-mesh dust. Propagation was obtained in test 564 with a mixture containing 57.5 per cent incombustible material (50 per cent shale), but was not obtained in test 535 with a mixture containing 66 per cent incombustible material (60 per cent shale), no gas being present in either test. The 40–60 coal-shale mixture was tried again in test 567 with 0.8 per cent gas, and a weak, slow explosion resulted. The flame extended to the end of the zone in the air course, but stopped 25 feet short in the entry. This mixture would undoubtedly give complete propagation with 1 per cent gas present. In test 533 a mixture containing 74.5 per cent incombustible (70 per cent shale) was tried with 0.8 per cent gas in the air current, and propagation was not obtained. This mixture would probably be safe with 1 per cent of gas present.

Propagation was not obtained in test 536 with a mixture containing 78.8 per cent incombustible (75 per cent shale) with 1.6 per cent gas present, but the flame extension was very long in the air course. The same mixture was tried with 2.4 per cent gas in test 568, and complete propagation was not obtained, as the flame stopped 75 feet short of the end of the zone on the main entry. However, as propagation was complete in the air-course zone, it would be best to set about 82 per cent as the content of incombustible required to prevent propagation with this coal dust in 2 per cent of gas.

For purposes of comparison one propagation test was made with pulverized dust in order to obtain an indication of the maximum explosibility of the dust. Propagation was not obtained in test 570 with a mixture containing 78.8 per cent incombustible (75 per cent shale) and no gas present.

CONCLUSIONS ON EXPLOSIBILITY OF DUST FROM NO. 5 BED FROM TESTS OF NO. 3 SAMPLE

Like samples 1 and 2, these tests show that this dust has very nearly the same degree of explosibility as Pittsburgh coal dust. The amount of incombustible material necessary to prevent ignition and propagation of 20-mesh dust, 20 per cent of which will pass 200-mesh, under various conditions, is as follows:

Incombustible material needed to prevent ignition or propagation in coal dust from No. 5 bed

Condition	Gas used	Incombustible in mixture	Rock dust in mixture
	Per cent	*Per cent*	*Per cent*
Nonignition	0	41	30
Do	1	51	42
Do	2	63	57
Nonpropagation	0	66	60
Do	1	75	70
Do	2	82	79

Application to field conditions.—The mine from which the sample came was liberating a great deal of fire damp. The ventilation needed to be increased, but even then the dust should be made inert in the presence of 1 per cent of gas. To prevent propagation in the presence of 1 per cent of gas requires 75 per cent inert material in the dust. The moisture and ash content of the road and rib dusts collected varied from 21 to 61 per cent, and with all of these it would be necessary to add from one to two or more parts of rock dust to each part of coal dust, in order to prevent propagation of an explosion.

The mine was reported as being naturally damp, yet there was so little free water present that a pump was not required. It is probable that as the mine becomes larger the workings will tend to become drier, as in other mines of that district, and increased ventilation will be needed to remove the fire damp. Under these conditions it is desirable to keep the mine thoroughly rock dusted.

EXPLOSIBILITY TESTS OF COAL DUST FROM NO. 9 BED, UNION COUNTY, KY.

Three ignition tests and three propagation tests were made of 20-mesh dust prepared from a 5-ton sample of run-of-mine coal obtained from a mine working No. 9 bed in Union County, Ky. This dust was so prepared that 20 per cent would pass a 200-mesh screen, and was about 3 per cent finer than the average of the dusts collected in the mine.

CONDITIONS IN MINE WHERE SAMPLE WAS OBTAINED

A standard explosion-hazard investigation was made of the mine. Six standard face samples of the coal were taken, and analyses of these are given in Table 28.

TABLE 28.—*Analyses of face samples of coal from a Kentucky mine working No. 9 bed*

Laboratory No.	Coal as received				Moisture plus ash	Ratio, $\frac{V}{V+FC}$
	Moisture	Volatile matter	Fixed carbon	Ash		
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	
96079	2.9	35.9	52.1	9.1	12.0	40.8
96082	3.2	35.8	51.6	9.4	12.6	40.9
96084	3.2	37.1	50.6	9.1	12.3	42.3
96083	2.9	36.6	50.4	10.1	13.0	42.1
96081	2.9	37.5	50.8	8.8	11.7	42.4
96080	3.0	38.3	50.6	8.1	11.1	43.0

The analyses of a composite of these samples are as follows:

Analyses of composite sample

[Coal as received]

Proximate analysis:	Per cent	Ultimate analysis:	Per cent
Moisture	3.0	Hydrogen	5.3
Volatile matter	36.8	Carbon	73.1
Fixed carbon	51.1	Nitrogen	1.5
Ash	9.1	Oxygen	7.8
Moisture plus ash	12.1	Sulphur	3.2
Ratio of volatile to total combustible	41.8	Ash	9.1

Road and rib dust samples were collected in eight places in the mine, and the corresponding road and rib dusts were combined into a single sample in the mine. The results of the analyses and sizing tests of these samples are given in Table 29.

TABLE 29.—*Analyses and sizing tests of combined road and rib dusts from a Kentucky mine working No. 9 bed*

Laboratory No.	Analysis as received				Moisture plus ash	Percentage of 20-mesh material through—	
	Moisture	Volatile matter	Fixed carbon	Ash		100-mesh screen	200-mesh screen
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*		
96086	6.1	26.9	37.8	29.2	35.3	38.9	24.5
96087	9.3	31.2	41.6	17.9	27.2	5.9	1.2
96088	5.9	22.1	42.3	19.7	25.6	37.4	35.6
96089	4.4	21.2	25.1	49.3	53.7	34.7	18.4
96090	10.2	28.7	38.1	23.0	33.2	13.4	9.8
96091	10.1	23.3	30.8	35.8	45.9	15.6	3.6
96092	4.9	27.0	33.6	34.5	39.4	32.2	25.5
96093	2.8	19.8	26.0	51.4	54.2	32.9	17.0

The average moisture and ash content of these samples is 39.3 per cent, and the average quantity of 200-mesh dust present is 16.9 per cent.

Samples of mine air collected in nine places showed a maximum of 0.23 per cent methane. Computations showed that the most gaseous section of the mine was giving off about 57,000 cubic feet of methane in 24 hours. The ventilation of the mine was adequate at the time of the investigation, but should it be interrupted or not properly carried to the face, accumulations of gas would certainly form.

DETAILS OF EXPLOSION TESTS

Procedure and results.—Three ignition tests were made with 20-mesh dust without gas. Three propagation tests were made with 20-mesh dust, one being without gas and two with gas in the air current.

The average of the analyses of the 20-mesh coal dust from No. 9 bed, just before mixing for the tests, was as follows:

Average of analyses of 20-mesh coal dust from No. 9 bed

Constituents:	Per cent
Moisture	2. 6
Volatile matter	36. 3
Fixed carbon	48. 5
Ash	12. 6
Moisture plus ash	15. 2
Ratio of volatile to total combustible	42. 8

All tests were to be made of dust 20 per cent of which would pass 200-mesh, but one of the testing sieves was damaged accidentally. Before this was discovered, test 613 had been made with dust somewhat finer than the standard. The average of the sizing tests of the coal dust and shale dust was as follows:

Average of sizing tests of coal dust used

Material	Through 20-mesh	Through 48-mesh	Through 100-mesh	Through 200-mesh
20-mesh coal dust, test 613	99. 9	79. 2	38. 4	26. 8
20-mesh coal dust, other tests	99. 1	80. 4	37. 6	20. 0

The results of the explosion tests are given in Table 30.

TABLE 30.—*Results of standard tests of 20-mesh, 20 per cent 200-mesh, coal dust from No. 9 bed, Union County, Ky.*

IGNITION TESTS

Test No.	Date, 1923–24	Ratio of coal dust to shale dust in mixture	Mixed dust: Calculated incombustible content, per cent	Mixed dust: Rate of loading, pounds per foot	Mixed dust: Total loading, pounds	Natural gas used, per cent	Records obtained in entry or air course	Maximum pressure, pounds per square inch: Station 1150	Maximum pressure, pounds per square inch: Station 950	Time of tin-foil rupture at station E 1250, second	Flame velocity between stations, feet per second: Station 1250 to station 1150	Flame velocity: Station 1150 to station 1050	Flame velocity: Station 1050 to station 950	Length of flame measured from cannon, feet	Remarks
615	Dec. 21	(1)	15.2	1.00	750	0.0	Entry		18	0.467	199	629	1,176	(2)	Ignition obtained.
							Air course	23	29			483	658	(2)	
618	Jan. 2	80:20	32.2	1.25	937.5	.0	Entry	3	3			218	478	(2)	Do.
							Air course	3	5			164	249	(2)	
613	Dec. 13	70:30	40.6	1.43	1,071	.0	Entry	1	1	.825				100	Ignition not obtained.
							Air course	1	0					150	

PROPAGATION TESTS

Test No.	Date, 1923–24	Ratio of coal dust to shale dust in mixture	Mixed dust: Calculated incombustible content, per cent	Mixed dust: Rate of loading, pounds per foot	Mixed dust: Total loading, pounds	Natural gas used, per cent	Records obtained in entry or air course	Maximum pressure, pounds per square inch: Station 1150	Maximum pressure, pounds per square inch: Station 950	Time of tin-foil rupture at station E 1250, second	Flame velocity between stations, feet per second: Station 1250 to station 1150	Flame velocity: Station 1150 to station 1050	Flame velocity: Station 1050 to station 950	Length of flame measured from cannon, feet	Remarks
619	Jan. 4	50:50	57.6	2.00	1,300	0.0	Entry	2	1	0.164	94	34		225	Propagation not obtained.
							Air course	1	2					300	
620	Jan. 9	40:60	66.1	2.50	1,625	1.0	Entry	6	3			208		(2)	Propagation obtained.
							Air course	3	3			134	45	(2)	
621	Jan. 11	35:65	70.3	3.86	1,857	1.1	Entry	(3)		(3)				300	Propagation not obtained.
							Air course							375	

[1] All coal. [2] Flame extended through zones. [3] No pressure or flame velocity records obtained.

Discussion of results.—Ignition was obtained in test 615 with pure 20-mesh coal dust from No. 9 bed, and the explosion was strong and rapid. Ignition was also obtained in test 618 with a mixture containing 32.2 per cent incombustible (20 per cent shale), but was not obtained in test 613 with a mixture containing 40.6 per cent incombustible (30 per cent shale). No gas was present in any ignition tests.

Propagation was not obtained in test 619 with a mixture containing 57.6 per cent incombustible (50 per cent shale), and no gas present. Propagation was obtained in test 620 with a mixture containing 66.1 per cent incombustible (60 per cent shale), and 1 per cent gas in the air current, but the explosion was rather weak. In test 621 a mixture containing 70.3 per cent incombustible (65 per cent shale) was tried with 1.1 per cent gas in the air current, and propagation was not obtained, although the flame extended to within 25 feet of the end of the air-course zone and within 50 feet of the end of the entry zone. It is best to consider 71 per cent incombustible as the limit of explosibility for this dust with 1 per cent gas present.

CONCLUSIONS ON EXPLOSIBILITY OF DUST FROM NO. 9 BED

The tests show that dust from Kentucky No. 9 bed is explosive. The amount of incombustible material necessary to prevent propagation of an explosion is 58 per cent with no gas present, and 71 per cent with 1 per cent gas present. The incombustible content must be 40 per cent to prevent direct ignition of the dust by a blown-out shot of 4 pounds of black blasting powder in the absence of gas. The dust appears to be slightly less explosive than Pittsburgh coal dust, despite the fact that its ratio of volatile to total combustible is 2.8 per cent higher, and it carries very little more moisture than Pittsburgh coal does.

Application to field conditions.—As the mine from which the sample was taken liberated considerable fire damp, it would be best to keep the road and rib dusts inert in the presence of 1 per cent of gas, and to do this would require that 71 per cent incombustible material be present. None of the dusts collected contained this amount, and they required the addition of one to two parts of rock dust for each part of road or rib dust present in order to bring the incombustible content up to the safe limit. Thorough rock dusting would be the proper solution of the problem.

103804°—27——7

EXPLOSIBILITY TESTS OF COAL DUST FROM JAGGER BED, WALKER COUNTY, ALA.

Five propagation tests and one ignition test were made of 20-mesh dust prepared from a 5-ton sample of run-of-mine coal obtained from a mine working the Jagger bed, Walker County, Ala. The dust was so prepared that 20 per cent would pass a 200-mesh screen, which is approximately the average size of the road and rib dusts collected in the mine.

CONDITIONS IN MINE WHERE SAMPLE WAS OBTAINED

A standard explosion-hazard investigation of the mine was made. Five face samples of the coal were taken, the analyses of which are given in Table 31.

TABLE 31.—*Analyses of face samples of coal from an Alabama mine working the Jagger bed*

Laboratory No.	Coal as received				Moisture plus ash	Ratio, $\frac{V}{V+FC}$
	Moisture	Volatile matter	Fixed carbon	Ash		
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	
79608	3.2	34.7	49.7	12.4	15.6	41.1
79609	3.5	34.5	51.9	10.1	13.6	39.9
79610	6.7	33.4	50.5	9.4	16.1	39.8
79611	4.0	34.5	52.0	9.5	13.5	39.8
79612	3.6	33.2	51.3	11.9	15.5	39.2

The analyses of a composite of these samples are as follows:

Analyses of composite sample

[Coal as received]

Proximate analysis:	Per cent	Ultimate analysis:	Per cent
Moisture	4.3	Hydrogen	5.2
Volatile matter	33.8	Carbon	69.6
Fixed carbon	51.2	Nitrogen	1.6
Ash	10.7	Oxygen	12.1
Moisture plus ash	15.0	Sulphur	.8
Ratio of volatile to total combustible	39.8	Ash	10.7

Ten road-dust and five rib-dust samples were collected. Conditions were such that the latter could not be obtained at every point where a road-dust sample was taken. The results of the analyses and sizing tests of these samples are given in Table 32.

TABLE 32.—*Analyses and sizing tests of road dust and rib dust from an Alabama mine working the Jagger bed*

Laboratory No.	Kind of dust	Analysis as received				Moisture plus ash	Percentage of 20-mesh material through—	
		Moisture	Volatile matter	Fixed carbon	Ash		100-mesh screen	200-mesh screen
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*		
94821	Road dust	7.0	19.6	31.2	42.2	49.2	19.0	9.5
94822	do	3.2	10.2	14.9	71.7	74.9	20.3	13.5
94823	do	7.7	25.7	38.7	27.9	35.6	17.7	6.3
94824	do	7.8	22.7	36.9	32.6	40.4	18.0	13.6
94825	do	4.3	20.1	32.8	42.8	47.1	28.5	15.0
94828	do	5.3	15.2	21.2	58.3	63.6	19.2	11.1
94829	do	4.0	15.7	21.8	58.3	62.5	26.2	14.8
94830	do	8.8	21.1	31.4	38.7	47.5	8.8	4.5
94827	do	13.0	18.5	31.0	37.5	50.5	15.0	9.1
94826	do	6.4	18.3	30.9	44.4	50.8	22.6	16.9
94831	Rib dust	7.2	19.8	30.3	42.7	49.9	62.7	47.7
94832	do	6.6	25.0	46.0	22.4	29.0	84.1	64.1
94835	do	5.6	24.4	37.1	32.9	38.5	84.7	68.3
94834	do	6.4	22.8	32.4	38.4	44.8	38.7	25.2
94833	do	6.7	24.3	35.7	33.3	40.0	32.4	17.1

All the road dusts are fairly high in ash and are rather coarse, as none sieved more than 17 per cent through a 200-mesh screen. The rib dusts are more variable in composition and size. The exact relation of the road and rib dusts is not known, but from the work done in other mines it is estimated that the average amount of dust passing 200-mesh will not greatly exceed 20 per cent.

Nine samples of mine air were collected. The maximum methane content was 0.67 per cent in a sample taken near the face of an entry with no air movement. The main return showed not more than 0.04 per cent methane. These facts show that a small quantity of fire damp was being liberated, and the principal need was to carry more air to the faces. The probabilities were that more gas would be encountered as the mine advanced under heavier cover.

DETAILS OF EXPLOSION TESTS

Procedure and results.—Five propagation tests were made of 20-mesh dust, three without gas and two with gas present. One ignition test was made of 20-mesh dust with no gas present. The average of the analyses of the 20-mesh coal dust just before mixing for the tests was as follows:

Average of analyses of 20-mesh coal dust from the Jagger bed

Constituents:	Per cent
Moisture	3.5
Volatile matter	32.0
Fixed carbon	53.3
Ash	11.2
Moisture plus ash	14.7
Ratio of volatile to total combustible	37.5

Table 33.—*Results of standard tests of 20-mesh, 20 per cent 200-mesh, coal dust from the Jagger bed, Walker County, Ala.*

IGNITION TEST

Test No.	Date, 1923	Ratio of coal dust to shale dust in mixture	Mixed dust: Calculated incombustible content, per cent	Mixed dust: Rate of loading, pounds per foot	Mixed dust: Total loading, pounds	Natural gas used, per cent	Records obtained in entry or air course	Maximum pressure, pounds per square inch: Station 1150	Maximum pressure, pounds per square inch: Station 950	Time of tin-foil rupture at station E1250, seconds	Flame velocity between stations, feet per second: Station 1250 to station 1150	Flame velocity between stations, feet per second: Station 1150 to station 1050	Flame velocity between stations, feet per second: Station 1050 to station 950	Length of flame measured from cannon, feet	Remarks
610	Dec. 7	80:20	[1] 31.5	1.25	937.5	0.0	Entry	1	½	2.863				100	Ignition not obtained.
							Air course	½	½					175	

PROPAGATION TESTS

Test No.	Date, 1923	Ratio of coal dust to shale dust in mixture	Mixed dust: Calculated incombustible content, per cent	Mixed dust: Rate of loading, pounds per foot	Mixed dust: Total loading, pounds	Natural gas used, per cent	Records obtained in entry or air course	Maximum pressure, pounds per square inch: Station 1150	Maximum pressure, pounds per square inch: Station 950	Time of tin-foil rupture at station E1250, seconds	Flame velocity between stations, feet per second: Station 1250 to station 1150	Flame velocity between stations, feet per second: Station 1150 to station 1050	Flame velocity between stations, feet per second: Station 1050 to station 950	Length of flame measured from cannon, feet	Remarks
611	Dec. 8	80:20	[1] 31.5	1.25	812.5	0.0	Entry	6	3	0.395	151	101		(2)	Propagation obtained.
							Air course	4	5				[3] 353	(2)	
612	Dec. 12	70:30	[1] 40.0	1.43	928	.0	Entry	1	1					150	Propagation not obtained.
							Air course	2	1					225	
608	Dec. 3	50:50	57.2	2.00	1,300	.0	Entry	1	1	.583				125	Do.
							Air course	1	1					150	
609	Dec. 5	50:50	57.2	2.00	1,300	1.1	Entry	2	2	.238	104	67		275	Complete propagation not obtained.
							Air course	4	4			109	88	(2)	
617	Dec. 28	40:60	65.8	2.50	1,625	1.0	Entry	1	1	.231	98			175	Propagation not obtained.
							Air course	1	1					300	

[1] In this test 11.5 per cent of the 20-mesh coal dust passed through 200-mesh instead of 20 per cent, as in tests 608, 609, and 617.
[2] Flame extended through zones.
[3] Velocity from station A1150 to station A950.

It was intended that the coal dust used in these tests should measure 20 per cent through 200-mesh, but undiscovered accidental damage to a testing sieve resulted in three of the tests being made with dust having only 11.5 per cent of 200-mesh. The actual size of the dust used in the tests is as follows:

Sizing tests of coal dust used

Material	Through 20-mesh	Through 48-mesh	Through 100-mesh	Through 200-mesh
	Per cent	*Per cent*	*Per cent*	*Per cent*
20-mesh coal dust, tests 608 and 609	98.4	65.3	33.5	20.0
20-mesh coal dust, tests 610, 611, and 612	99.2	69.4	27.4	11.5
20-mesh coal dust, test 617	99.3	72.9	35.1	20.0

The results of the explosion tests are given in Table 33.

Discussion of results.—Tests 611 and 612 were propagation tests with 20-mesh dust of which only 11.5 per cent would pass 200-mesh. Propagation was obtained in test 611 with a mixture containing 31.5 per cent incombustible (20 per cent shale), but was not obtained in test 612 with a mixture containing 40 per cent incombustible (30 per cent shale); no gas was present in either test. Tests 608, 609, and 617 were made with 20-mesh dust, of which 20 per cent would pass 200-mesh. Propagation was not obtained in test 608 with a mixture containing 57.2 per cent incombustible material (50 per cent shale) with no gas present. Complete propagation was not obtained in test 609 with a 50–50 coal-shale mixture containing 57.2 per cent incombustible, with 1.1 per cent gas in the air current. The flame traveled to the end of the zone in the air course, but stopped 75 feet short in the entry. This mixture is not safe in the presence of 1 per cent gas. Propagation was not obtained in test 617 with a mixture containing 65.8 per cent incombustible material (60 per cent shale) with 1 per cent gas present.

Only one ignition test was made. Ignition was not obtained in test 610 with a mixture containing 31.5 per cent incombustible (20 per cent shale) with no gas present, but the coal dust was of such fineness that only 11.5 per cent would pass through 200-mesh, instead of 20 per cent as intended. This mixture would probably give ignition with the finer size of dust.

CONCLUSIONS ON EXPLOSIBILITY OF DUST FROM JAGGER BED

The tests showed that the pure dust is explosive, and admixture of inert material is necessary to prevent propagation of an explosion in this dust. There must be 55 per cent of inert material present to prevent propagation of an explosion through 20-mesh, 20 per cent 200-mesh, dust when there is no gas present, and 65 per cent inert material must be present in this dust when 1 per cent of gas is present.

This coal dust is less explosive than Pittsburgh coal dust. The ratio of volatile to total combustible is lower, and the coal carries a little more moisture than does Pittsburgh coal dust.

Application to field conditions.—As there was some fire damp in the mine from which the sample was taken, it would be safe to keep 65 per cent of inert material in the dust, with the possible exception that 55 per cent might be safe on intake airways before the live workings were reached. The percentage of moisture and ash in the road and rib dusts is fairly high, but with one exception all of these dusts would propagate an explosion when 1 per cent of gas was present. However, adding one part of rock dust to one part of the most explosive of the samples would render it safe.

EXPLOSIBILITY TESTS OF COAL DUST FROM SILKSTONE BED, YORKSHIRE, ENGLAND

Seven ignition tests and six propagation tests were made of pulverized dust prepared from a 10-ton sample of nut coal shipped from a mine working the Silkstone bed in Yorkshire, England. Dust prepared from this coal has been the standard of explosibility in British investigations, much as Pittsburgh coal dust has been the standard in American investigations. The testing of this dust was the first step in the cooperative program between the Bureau of Mines and the British Safety in Mines Research Board. The purpose of the test was to obtain a standard of comparison in coal-dust explosibility testing. For this reason there was no mine explosion-hazard investigation, and the coal dust was tested in the size regularly used at the experimental station at Eskmeals, England. Ten of the tests were made in March, 1924, and the other three in April, 1925.[19]

DETAILS OF EXPLOSION TESTS

Procedure and results.—Seven ignition tests were made with pulverized dust, three being without gas and four with gas in the air current. Six propagation tests were made with pulverized dust, three being without gas and three with gas present. The average of the analyses of the pulverized coal dust from the Silkstone bed, just before mixing for the tests, was as follows:

Average analysis of pulverized coal dust from the Silkstone bed

Constituents:	Per cent
Moisture	3. 9
Volatile matter	34. 5
Fixed carbon	57. 6
Ash	4. 0
Moisture plus ash	7. 9
Ratio of volatile to total combustible	37. 4

[19] Henry Walker, deputy chief inspector of mines, Prof. R. V. Wheeler, director of the Eskmeals station, and his assistant, W. R. Chapman, visited the experimental mine during the testing period in 1924. Messrs. Wheeler and Chapman again visited the mine in 1925 with E. J. Foley, assistant undersecretary of mines.

An ultimate analysis of one sample gave the following result:

Ultimate analysis of Silkstone coal

Constituents:	Per cent
Hydrogen	5. 5
Carbon	76. 5
Nitrogen	1. 7
Oxygen	10. 9
Sulphur	1. 7
Ash	3. 7

The coal dust was to be so prepared that 85 per cent would pass a 200-mesh sieve (I. M. M.),[20] which is the standard used in testing at Eskmeals. No such sieve could be obtained in Pittsburgh, and a 250-mesh Tyler sieve (American)[21] was substituted; the openings in this sieve are theoretically larger than those in the I. M. M. sieve, in the ratio of 61 to 60. The comparative size (American standard-scale sieves) of the dust used is as follows:

Average of sizing tests of coal dust and shale dust used

Material	Through 100-mesh	Through 200-mesh	Through 250-mesh
	Per cent	*Per cent*	*Per cent*
Pulverized coal dust, tests 625–629	99. 4	91. 9	85. 0
Pulverized coal dust, tests 630–632	99. 5	87. 5	85. 2
Pulverized coal dust, tests 633–634	99. 8	93. 8	90. 4
Pulverized coal dust, tests 700, 702, 703	99. 6	94. 6	94. 4
Pulverized shale dust, all tests	100. 0	97. 3	96. 4

The results of the explosion tests are given in Table 34.

[20] Report of Committee on Standardization of Screens: Bull. 38, Inst. Min. and Met., 1907. Also see Stadler, H., "Grading analyses and their application": Trans. Inst. Min. and Met., vol. 19, 1909–10, Table A, p. 479.

[21] Gross, John, "A proposed standard sizing test": Rept. to Committee on Milling Methods, Inst. Min. and Met., 1925, p. 3.

TABLE 34.—*Results of standard tests of pulverized coal dust from the Silkstone bed, Yorkshire, England*

IGNITION TESTS

Test No.	Date	Ratio of coal dust to shale dust in mixture	Mixed dust: Calculated incombustible content, per cent	Mixed dust: Rate of loading, pounds per foot	Mixed dust: Total loading, pounds	Natural gas used, per cent	Records obtained in entry or air course	Maximum pressure, pounds per square inch: Station 1150	Maximum pressure, pounds per square inch: Station 950	Time of tinfoil rupture at station E 1250, seconds	Flame velocity between stations, feet per second: Station 1250 to station 1150	Flame velocity between stations, feet per second: Station 1150 to station 1050	Flame velocity between stations, feet per second: Station 1050 to station 950	Length of flame measured from cannon, feet	Remarks
625	Feb. 28, 1924	50:50	54.0	2.00	1,500	0.0	Entry	26	19	0.717	126	1,639	588	(1)	Ignition obtained.
							Air course	19	14			418	1,220	(1)	
626[2]	Mar. 1, 1924	50:50	54.0	2.00	1,500	.0	Entry	1	1	1.413				100	Ignition not obtained.
							Air course		½					150	
627	Mar. 3, 1924	40:60	63.2	2.50	1,875	.0	Entry	½	½					50	Do.
							Air course	½	½						
629	Mar. 5, 1924	40:60	63.2	2.50	1,875	1.6	Entry	30	23			667	3,030	(1)	Ignition obtained.
							Air course	20	25			719	1,282	(1)	
702	Apr. 24, 1925	35:65	67.8	2.86	2,145	1.1	Entry	1	1	1.243	32			100	Ignition not obtained.
							Air course	1	1					200	
630	Mar. 7, 1924	30:70	72.4	3.33	2,417	1.5	Entry	½	½					25	Do.
							Air course	½	½						
632	Mar. 12, 1924	30:70	72.4	3.33	2,417	1.8	Entry	½	½					25	Do.
							Air course	½	½						

PROPAGATION TESTS

Test No.	Date	Ratio of coal dust to shale dust in mixture	Mixed dust: Calculated incombustible content, per cent	Mixed dust: Rate of loading, pounds per foot	Mixed dust: Total loading, pounds	Natural gas used, per cent	Records obtained in entry or air course	Maximum pressure, pounds per square inch: Station 1150	Maximum pressure, pounds per square inch: Station 950	Time of tinfoil rupture at station E 1250, seconds	Flame velocity between stations, feet per second: Station 1250 to station 1150	Flame velocity between stations, feet per second: Station 1150 to station 1050	Flame velocity between stations, feet per second: Station 1050 to station 950	Length of flame measured from cannon, feet	Remarks
628	Mar. 3, 1924	40:60	63.2	2.50	1,625	0.0	Entry			0.475	372	544	1,563	(1)	Propagation obtained.
							Air course					380	1,177	(1)	
631	Mar. 7, 1924	30:70	72.4	3.33	2,167	.0	Entry	3	2				[3] 131	(1)	Do.
							Air course	3	2			156	199	(1)	
703	Apr. 25, 1925	25:75	77.0	4.00	2,600	.0	Entry	1	1	.430	26			125	Propagation not obtained.
							Air course	1	1					175	
633	Mar. 14, 1924	25:75	77.0	4.00	2,600	1.1	Entry	6	5	.220	134	297	481	(1)	Propagation obtained.
							Air course	5	5			228	641	(1)	
634	Mar. 20, 1924	20:80	81.6	5.00	3,250	1.5	Entry	1	1	.237	92			175	Propagation not obtained.
							Air course	1	1					250	
700	Apr. 22, 1925	20:80	81.6	5.00	3,250	1.9	Entry	2	2	.213	90		[3] 68	(1)	Propagation obtained.
							Air course	2	2			125	210	(1)	

[1] Flame extended through zones. [2] The charge of powder in the cannon was reduced to 1½ pounds for this test only. [3] Velocity from station E 1150 to station E 950.

Discussion of ignition tests.—Ignition was obtained in test 625 with a mixture containing 54 per cent incombustible material (50 per cent shale), with no gas present.

In order to make further comparison with the work done at Eskmeals, a similar mixture was prepared and used in test 626, but the charge of powder in the cannon was 1½ pounds instead of the usual 4 pounds. Ignition was not obtained with this reduced charge of powder.[22] This was the only test in the series that departed in any way from the standard methods. In test 627 ignition was not obtained with a mixture containing 63.2 per cent incombustible (60 per cent shale), and no gas present, but when a similar mixture was tried in test 629 with 1.6 per cent of gas, a very strong and rapid explosion resulted. Ignition was not obtained in test 702 with a mixture containing 67.8 per cent incombustible (65 per cent shale), 1.1 per cent gas being present. Ignition was not obtained in test 630 with a mixture containing 72.4 per cent incombustible (70 per cent shale), with 1.5 per cent of gas in the air current, nor was it obtained in test 632 with a similar mixture and 1.8 per cent of gas. The length of flame in these two tests was only 25 feet, the same as the length of a cannon flame in a dustless zone. In view of this fact this mixture probably would not give ignition with 2 per cent gas present.

Discussion of propagation tests.—Propagation was obtained in test 628 with a mixture containing 63.2 per cent incombustible material (60 per cent shale) and was also obtained in test 631 with a mixture containing 72.4 per cent incombustible material (70 per cent shale); no gas was present in either test. Propagation was not obtained in test 703 with a mixture containing 77 per cent incombustible material (75 per cent shale) and no gas present, but was obtained in test 633 with a similar mixture and 1.1 per cent gas present. Propagation was not obtained in test 634 with a mixture containing 81.6 per cent incombustible (80 per cent shale), and 1.5 per cent gas in the air current. A similar mixture was tried in test 700 with 1.9 per cent gas, and propagation was obtained.

CONCLUSIONS ON EXPLOSIBILITY OF DUST FROM SILKSTONE BED

The results of these tests are in general accord with predictions based on the testing of pulverized dust of other coals at the experimental mine. As the Silkstone dust has a little more moisture and a lower ratio of volatile to total combustible than the Pittsburgh

---

[22] This result was similar to that obtained in early experimental mine tests with Pittsburgh dust before the present standard ignition and propagation tests had been developed. It was then deemed advisable to use a charge of black blasting powder (4 pounds) comparable with that then employed in many coal mines in the United States; in fact, the State law of Indiana still permits the use in a single shot of as much as 6 pounds of powder. It is desirable to make a further study of the effect of initiatory shots of different strengths.

dust, it might be predicted that the Silkstone dust would be the less explosive of the two, although the difference would be slight. On the other hand, the ash content is less than that of Pittsburgh dust. The limits of explosibility of the two dusts, as determined at the experimental mine, are the same within the limits of error of the large-scale testing work. From the results of the tests, the Silkstone coal might be slightly more explosive, but additional tests would be necessary before conclusions could be safely drawn.

In comparing the results of these tests of Silkstone dust with those of other dusts reported in this section it must be remembered that the Silkstone dust was pulverized and 87 to 97 per cent of it would pass through a 200-mesh sieve. Tests of the other coals were made primarily with dust of which 20 per cent passed 200-mesh. When pulverized dust was used at all in the tests with these coals, only one or two tests were made for comparison. The coarser size more nearly approximates natural mine dust. The pulverized size is found in mines only where dust has settled from the air on surfaces more or less elevated or protected from deposition of coarser sizes. However, tests with pulverized dust have been of value in the experimental work, and the present results with Silkstone coal should be compared with the results with pulverized Pittsburgh dust reported in Bulletin 167. It should be remembered that the explosibility limits for 20-mesh dust (of which 20 per cent passes 200-mesh) from a given coal, as measured by the percentage of inert matter required to prevent propagation of an explosion, are 10 to 15 per cent lower than the explosive limits for pulverized dust from the same coal.

EXPLOSIBILITY TESTS OF COAL DUST FROM NICKEL PLATE BED, JEFFERSON COUNTY, ALA.

Fifteen propagation and ignition tests were made of 20-mesh and pulverized dust prepared from a 5-ton sample of run-of-mine coal obtained from a mine working the Nickel Plate bed in Jefferson County, Ala. The 20-mesh dust was so prepared that 20 per cent would pass a 200-mesh screen. It was 7.5 per cent finer than the average of the road and rib dust samples collected, but this finer size, which would give some margin of safety, was thought preferable to dust that contained only 10 per cent of material that would pass through 200-mesh, the only other standard size available.

CONDITIONS IN MINE WHERE SAMPLE WAS OBTAINED

A standard explosion-hazard investigation of the mine was made. Five face samples of the coal were taken, and analyses of these are given in Table 35.

TABLE 35.—*Analyses of face samples of coal from an Alabama mine working the Nickel Plate bed*

Laboratory No.	Coal as received				Moisture plus ash	Ratio, $\frac{V}{V+FC}$
	Moisture	Volatile matter	Fixed carbon	Ash		
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	
33913	3.2	25.6	67.2	4.0	7.2	27.6
33914	2.3	25.0	67.7	5.0	7.3	26.9
33915	2.3	25.3	67.7	4.7	7.0	27.2
33916	2.5	25.7	66.6	5.2	7.7	27.8
33917	2.3	24.2	67.8	5.7	8.0	26.4

The analyses of a composite of these samples are as follows:

Analyses of composite sample

[Coal as received]

Proximate analysis:	Per cent	Ultimate analysis:	Per cent
Moisture	2.6	Hydrogen	5.0
Volatile matter	24.8	Carbon	82.5
Fixed carbon	67.7	Nitrogen	1.6
Ash	4.9	Oxygen	5.2
Moisture plus ash	7.5	Sulphur	0.8
Ratio of volatile to total combustible	26.8	Ash	4.9

Six road-dust and three rib-dust samples were collected. Results of the analyses and sizing tests of these samples are given in Table 36.

TABLE 36.—*Analyses and sizing tests of road dust and rib dust from an Alabama mine working the Nickel Plate bed*

Laboratory No.	Kind of dust	Analysis as received				Moisture plus ash	Percentage of 20-mesh material through—	
		Moisture	Volatile matter	Fixed carbon	Ash		100-mesh screen	200-mesh screen
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*		
34007	Road dust	6.0	19.3	42.0	32.7	38.7	29.0	15.6
34008	do	11.1	21.3	57.6	10.0	21.1	14.1	8.2
34009	do	4.1	18.1	42.9	34.9	39.0	22.7	10.9
34011	do	8.7	23.2	58.5	9.6	18.3	10.2	3.7
34013	do	2.9	10.6	22.6	63.9	66.8	17.7	9.9
34015	do	3.7	24.2	58.0	14.1	17.8	46.1	32.5
34010	Rib dust	6.2	23.3	60.0	10.5	16.7	12.8	3.9
34012	do	6.2	23.1	52.0	18.7	24.9	11.6	1.9
34014	do	2.8	23.5	53.1	20.5	23.4	23.6	13.6

Consideration of the relative weights of the road dust and rib dust obtained showed that the moisture content averaged 5.9 per cent; the ash content, 26.2 per cent; and the content of 200-mesh dust, 12.5 per cent.

Duplicate samples of mine air were collected in eight places. The maximum amount of methane found was 1.34 per cent, in a sample of still air taken near the face of an entry. The main return carried a maximum of 0.44 per cent methane. As the total volume of air was over 115,000 cubic feet per minute, it can be seen that the mine was liberating large quantities of gas; the computed total is 700,000 cubic feet of pure methane every 24 hours. Evidently the greatest care was necessary to insure a continuous supply of fresh air at all points in the mine.

DETAILS OF EXPLOSION TESTS

Procedure and results.—Six ignition tests were made with 20-mesh dust, three with gas and three without gas in the air current. Five propagation tests were made with 20-mesh dust, two without gas and three with gas. Two ignition tests and two propagation tests were made with pulverized dust without gas, in order to obtain the maximum explosibility of the dust for comparison with other dusts. The average of the analyses of the 20-mesh and pulverized coal dust from the Nickel Plate bed, sampled just before mixing for the tests, was as follows:

Average of analyses of 20-mesh and pulverized coal dust from the Nickel Plate bed

Constituents	20-mesh dust	Pulverized dust
	Per cent	*Per cent*
Moisture	1.3	0.7
Volatile matter	24.9	25.8
Fixed carbon	67.3	69.0
Ash	6.5	4.5
Moisture plus ash	7.8	5.2
Ratio of volatile to total combustible	27.0	27.2

The average of the sizing tests of the coal dust used was as follows: Through 20-mesh, 98.8 per cent; through 48-mesh, 71.2 per cent; through 100-mesh, 38.1 per cent; and through 200-mesh, 20 per cent. Of the pulverized dust 99.2 per cent passed 100-mesh, and 92 per cent passed 200-mesh. The results of the test are given in Table 37.

Discussion of ignition tests with 20-mesh dust.—Ignition was obtained in test 582 with a mixture containing 26.2 per cent incombustible (20 per cent shale) but was not obtained in test 573 with a mixture containing 35.5 per cent incombustible (30 per cent shale); no gas was present in either test. Test 583 was a duplicate of test 573 and was made as a demonstration before a delegation of Alabama operators. The results were the same as in test 573, with the exception that the flame extended less in the air-course zone. In test 584 ignition was obtained with a mixture containing 35.5 per cent incombustible (30 per cent shale), there being 1.1 per cent gas in the air current. Ignition was obtained in test 574 with a mixture containing 44.7 per cent incombustible material (40 per cent shale) and 1.3 per cent gas in the air current. Ignition was not obtained in test 575 with a mixture containing 63.1 per cent incombustible material with 2.2 per cent gas present.

Discussion of propagation tests with 20-mesh dust.—Propagation was obtained in test 585 with a mixture containing 53.9 per cent incombustible (50 per cent shale) but was not obtained in test 576 with a mixture containing 63.1 per cent incombustible (60 per cent shale); no gas was present in either test. The 40–60 coal-shale mixture was tried again in test 579 with 1.1 per cent gas present, and complete propagation was not obtained, as the flame stopped 50 feet short of the end of the zone in the entry. However, the gases were hot enough to burn the tin foil at station E 950 (see fig. 3), and the mixture must be classed as unsafe with 1 per cent gas present. Propagation was not obtained in test 578 with a mixture containing 72.3 per cent incombustible (70 per cent shale) with 1.1 per cent gas present, but was obtained in test 577 with a similar mixture and 1.9 per cent gas present.

Discussion of tests with pulverized dust.—Two ignition tests were made with pulverized dust. Ignition was obtained in test 580 with a mixture containing 52.6 per cent incombustible (50 per cent shale), but was not obtained in test 586 with a mixture containing 63.1 per cent incombustible (60 per cent shale); no gas was present in either test.

Two propagation tests were made with pulverized dust. Propagation was obtained in test 587 with a mixture containing 62.1 per cent incombustible (60 per cent shale), but was not obtained in test 581 with a mixture containing 71.6 per cent incombustible (70 per cent shale); no gas was present in either test.

CONCLUSIONS ON EXPLOSIBILITY OF DUST FROM NICKEL PLATE BED

The tests show that coal dust from the Nickel Plate bed is nearly as explosive as Pittsburgh coal dust. The quantity of rock dust required to prevent ignition and propagation of an explosion in mixtures of 20-mesh coal dust from the Nickel Plate bed, 20 per cent of which will pass 200-mesh, is as follows under various conditions:

Incombustible material needed to prevent ignition or propagation in coal dust from the Nickel Plate bed

Condition	Gas used	Incombustible in mixture	Rock dust in mixture
	Per cent	*Per cent*	*Per cent*
Nonignition	0	35	30
Do	1	50	46
Do	2	63	60
Nonpropagation	0	63	60
Do	1	72	70

TABLE 37.—*Results of standard tests of coal dust from the Nickel Plate bed, Jefferson County, Ala.*

IGNITION TESTS WITH 20-MESH, 20 PER CENT 200-MESH, DUST

Test No.	Date, 1920	Ratio of coal dust to shale dust in mixture	Mixed dust: Calculated incombustible content, per cent	Mixed dust: Rate of loading, pounds, per foot	Mixed dust: Total loading, pounds	Natural gas used, per cent	Records obtained in entry or air course	Maximum pressure, pounds per square inch: Station 1150	Maximum pressure: Station 950	Time of tin-foil rupture at station E 1250, seconds	Flame velocity between stations, feet per second: Station 1250 to station 1150	Flame velocity: Station 1150 to station 1050	Flame velocity: Station 1050 to station 950	Length of flame measured from cannon, feet	Remarks
582	Apr. 19	80:20	26.2	1.25	937.5	0.0	Entry	10	12	0.406	123	---	[1] 303	[2]	Ignition obtained.
							Air course	8	10	---	---	285	658	[2]	
573	Mar. 29	70:30	35.5	1.43	1,071	.0	Entry	1	1	3.236	---	---	---	75	Ignition not obtained
							Air course	1	1	---	---	---	---	175	
583	Apr. 20	70:30	35.5	1.43	1,071	.0	Entry	1	1	.703	---	---	---	75	Do.
							Air course	1	1	---	---	---	---	100	
584	Apr. 20	70:30	35.5	1.43	1,071	1.1	Entry	16	17	.989	455	400	909	[2]	Ignition obtained.
							Air course	12	16	---	---	559	943	[2]	
574	Mar. 30	60:40	44.7	1.67	1,250	1.3	Entry	5	5	[3]	---	---	---	[2]	Do.
							Air course	4	4	---	---	---	---	[2]	
575	Mar. 31	40:60	63.1	2.50	1,875	2.2	Entry	1	1	1.763	---	---	---	75	Ignition not obtained.
							Air course	1	1	---	---	---	---	125	

PROPAGATION TESTS WITH 20-MESH, 20 PER CENT 200-MESH, DUST

Test No.	Date, 1920	Ratio of coal dust to shale dust in mixture	Mixed dust: Calculated incombustible content, per cent	Mixed dust: Rate of loading, pounds, per foot	Mixed dust: Total loading, pounds	Natural gas used, per cent	Records obtained in entry or air course	Maximum pressure, pounds per square inch: Station 1150	Maximum pressure: Station 950	Time of tin-foil rupture at station E 1250, seconds	Flame velocity between stations, feet per second: Station 1250 to station 1150	Flame velocity: Station 1150 to station 1050	Flame velocity: Station 1050 to station 950	Length of flame measured from cannon, feet	Remarks
585	Apr. 22	50:50	53.9	2.00	1,300	0.0	Entry	3	4	0.278	118	143	55	[2]	Propagation obtained.
							Air course	4	4	---	---	253	306	[2]	
576	Apr. 1	40:60	63.1	2.50	1,625	.0	Entry	1	1	.378	46	---	---	150	Propagation not obtained.
							Air course	---	1	---	---	---	---	225	
579	Apr. 9	40:60	63.1	2.50	1,625	1.1	Entry	2	3	.267	181	115	422	300	Complete propagation not obtained.
							Air course	3	4	---	---	148	240	[2]	
578	Apr. 7	30:70	72.3	3.33	2,167	1.1	Entry	1	1	.243	106	---	---	150	Propagation not obtained
							Air course	1	1	---	---	---	---	250	
577	Apr. 5	30:70	72.3	3.33	2,167	1.9	Entry	2	3	.386	180	162	57	[2]	Propagation obtained.
							Air course	4	4	---	---	152	467	[2]	

IGNITION TESTS WITH PULVERIZED, 92 PER CENT 200-MESH, DUST

580	Apr. 12	50:50	52.6	2.00	1,500	0.0	Entry	13	17	0.584		[4] 117	1,724	(2)	Ignition obtained.
							Air course	9	13			495	641	(2)	
586	Apr. 23	40:60	63.1	2.50	[5] 1,605	.0	Entry	1	1	.751				75	Ignition not obtained.
							Air course	1	1					150	

PROPAGATION TESTS WITH PULVERIZED, 92 PER CENT 200-MESH, DUST

587	Apr. 23	40:60	62.1	2.50	(6)	0.0	Entry	6	7	0.425	173	260	457	(2)	Propagation obtained.
							Air course	7	9			305	1,961	(2)	
581	Apr. 16	30:70	71.6	3.33	2,167	.0	Entry	1	1	.358	41			200	Propagation not obtained.
							Air course	1	1			69		325	

[1] Velocity from station E 1150 to station E 950.
[2] Flame extended through zones.
[3] No tin-foil record obtained in this test.
[4] Velocity from station E 1250 to station E 1050.
[5] Dust loaded to A 1004 and E 1004 only.
[6] Residue of test 586 plus 186 pounds of fresh dust from E 1250 to E 1157 and A 1207

Application to field conditions.—The mine from which this sample came had an efficient watering system installed in certain entries, but other entries were not treated and the dust in these was explosive. On account of the large amount of fire damp liberated in this mine, it would be advisable to render the dust inert in the presence of 1 per cent of gas. In entries that were not watered it would be necessary to keep 72 per cent of inert material in the dust to prevent propagation of an explosion. In watered entries it would be advisable to scatter rock dust on the floor to keep the ash content high and reduce the amount of water needed, and also to help wet by contact[23] the coal dust washed down from the ribs and roof.

The road and rib dust samples collected would all propagate an explosion with 1 per cent gas present and required up to 2 parts of added rock dust for each part of road or rib dust present to prevent propagation of an explosion with 1 per cent of gas present.

EXPLOSIBILITY TESTS OF COAL DUST FROM BECKLEY OR WAR CREEK BED, McDOWELL COUNTY, W. VA.

Three ignition and seven propagation tests were made of 20-mesh and pulverized dust prepared from a 5-ton sample of run-of-mine coal obtained from a mine working the Beckley or War Creek bed in McDowell County, W. Va. The 20-mesh dust was so prepared that 20 per cent would pass a 200-mesh screen, which is nearly the average size of the road and rib dust samples collected in the mine.

CONDITIONS IN MINE WHERE SAMPLE WAS OBTAINED

A standard explosion-hazard investigation of the mine was made. Six face samples of the coal were taken, and the analyses are given in Table 38.

TABLE 38.—*Analyses of face samples of coal from a West Virginia mine working the Beckley or War Creek bed*

Laboratory No.	Coal as received				Moisture plus ash	Ratio, $\frac{V}{V+FC}$
	Moisture	Volatile matter	Fixed carbon	Ash		
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	
A 4963	1.8	17.2	70.9	10.1	11.9	19.5
A 4964	1.9	17.5	69.3	11.3	13.2	20.2
A 4965	1.7	18.4	68.7	11.2	12.9	21.1
A 4966	1.6	17.2	71.8	9.4	11.0	19.3
A 4967	1.7	17.5	69.1	11.7	13.4	20.2
A 4968	1.6	17.6	69.7	11.1	12.7	20.2

23 See Bulletin 167, p. 407.

The analyses of a composite of these samples are as follows:

Analyses of composite sample

[Coal as received]

Proximate analysis:	Per cent	Ultimate analysis:	Per cent
Moisture	1.8	Hydrogen	4.4
Volatile matter	17.7	Carbon	78.9
Fixed carbon	69.7	Nitrogen	1.3
Ash	10.8	Oxygen	3.9
Moisture plus ash	12.6	Sulphur	.7
Ratio of volatile to total combustible	20.2	Ash	10.8

Seven road-dust and four rib-dust samples were collected. Results of the analyses and sizing tests of these samples are given in Table 39.

TABLE 39.—*Analyses and sizing tests of road dust and rib dust from a West Virginia mine working the Beckley or War Creek bed*

Laboratory No.	Kind of dust	Analysis as received				Moisture plus ash	Percentage of 20-mesh material through—	
		Moisture	Volatile matter	Fixed carbon	Ash		100-mesh screen	200-mesh screen
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*		
A 4970	Road dust	3.6	14.0	51.9	30.5	34.1	28.1	14.6
A 4972	do	7.0	11.9	37.5	43.6	50.6	9.3	3.2
A 4973	do	2.8	14.2	43.4	39.6	42.4	22.0	10.3
A 4974	do	6.1	16.7	60.9	16.3	22.4	14.2	4.5
A 4975	do	3.1	8.6	28.3	60.0	63.4	16.8	8.5
A 4977	do	3.4	14.1	46.0	36.5	39.9	22.9	11.5
A 4971	do	4.0	13.1	38.2	44.7	48.7	39.8	25.6
A 4976	Rib dust	1.5	19.1	69.9	9.5	11.0	95.2	82.5
A 4978	do	10.6	16.7	55.4	17.3	27.9	92.2	73.7
A 4979	do	26.8	12.9	45.4	14.9	41.7	48.7	35.0
A 4980	do	4.3	17.8	60.3	17.6	21.9	43.9	35.2

The road dusts are fairly high in ash with one exception, and only one had more than 15 per cent of dust that passed through 200-mesh. The rib dusts were much finer and carried much less ash than the road dusts, although one was very wet. The average content of 200-mesh dust for all samples was 20 per cent.

Samples of mine air were collected at five points. The maximum amount of methane was 0.55 per cent, in a volume of 11,000 cubic feet per minute. The total amount of methane liberated every 24 hours was computed as 200,000 cubic feet. Fire damp was evidently a hazard in this mine, although the quantity at any one point was not excessive at the time of the investigation.

DETAILS OF EXPLOSION TESTS

Procedure and results.—Three ignition tests were made with 20-mesh dust, two without gas and one with gas present. Seven propagation tests were made with 20-mesh dust, three without gas and four with gas present. Two additional propagation tests were made with pulverized dust without gas. The purpose of these latter tests was to check the results of previous tests with dust from the Beckley bed, which are reported in Bulletin 167, beginning on page 309. The average of the analyses of the dust prepared from Beckley coal, just before mixing for the tests, was as follows:

Average of analyses of coal dust from the Beckley or War Creek bed

Constituents:	Per cent
Moisture	1.0
Volatile matter	17.5
Fixed carbon	71.0
Ash	10.5
Moisture plus ash	11.5
Ratio of volatile to total combustible	19.8

The average of the sizing tests of the 20-mesh coal used was as follows: Through 20-mesh, 96.8 per cent; through 48-mesh, 76.4 per cent; through 100-mesh, 45.1 per cent; and through 200-mesh, 20 per cent. The pulverized coal dust averaged 99.2 per cent through 100-mesh and 89.4 per cent through 200-mesh. The results of the tests are given in Table 40 on pages 104 and 105.

Discussion of ignition tests with 20-mesh dust.—Ignition was not obtained in test 641, with a mixture containing 29.2 per cent incombustible material (20 per cent shale), or in test 642, with pure 20-mesh coal dust. No gas was used in either test. The pure dust was used with 1 per cent gas in the air current in test 643, and ignition was obtained. With the exception of the anthracites, this is the only coal ever tested at the experimental mine whose pure dust did not ignite directly from a blown-out shot in the absence of gas. Whether failure to ignite was due to the characteristics of the sample or to the surrounding physical conditions is uncertain. The dust could not be raised in a cloud as easily as the dust from most bituminous coals. Moreover, when a mass of dust was thrown into the air, it would tend to stay together in a solid mass rather than to disperse readily, and the whole mass would fall immediately to the ground. The cause of this behavior was not determined, but the dust was readily explosive when a suitable cloud was formed, as the propagation tests show.

Discussion of propagation tests with 20-mesh dust.—Propagation was obtained in test 647 with a mixture containing 29.2 per cent incombustible (20 per cent shale), and again in test 712 with a mixture containing 38.1 per cent incombustible (30 per cent shale). Propagation was not obtained in test 713 with a mixture containing 46.9 per cent incombustible (40 per cent shale). There was no gas present in any of the foregoing tests. The 80–20 coal-shale mixture was tested with 1 per cent gas in test 644, and a strong and rapid explosion resulted. Comparison of this explosion with the one obtained in test 647 shows the increased violence caused by the presence of gas.

In tests 645 and 646 the amount of incombustible in the mixture was increased to 38.1 and 46.9 per cent (30 and 40 per cent shale), respectively, with 1 and 1.1 per cent gas in the air current. Propagation was obtained in both tests, but each increase in the amount of shale in the mixture caused a decrease in the violence of the resulting explosion. Complete propagation was not obtained in test 649 with a mixture containing 55.8 per cent incombustible (50 per cent shale), with 1 per cent gas present, although this mixture is very close to the line. The flame traveled 300 feet in the main entry and reached the end of the zone in the air course, but with very low pressures and velocities. It would be best to consider 58 per cent as the amount of incombustible required to prevent propagation in the presence of 1 per cent gas. These tests showed that the dust was explosive even when gas was not present, and the wide difference in the results of the ignition and propagation tests is probably due mostly to the greater dust-raising power of the primary explosion developed in the 50-foot zone of Pittsburgh coal dust used in the propagation test.

Propagation tests with pulverized dust.—Propagation was obtained in test 648 with a mixture containing 55.5 per cent incombustible (50 per cent shale), but was not obtained in test 650 with a mixture containing 64.4 per cent incombustible (60 per cent shale); no gas was present in either test.

Test 648 is a duplicate of test 205, made in April, 1915 (see Bulletin 167, p. 312), except that the sample of Beckley coal tested then was from a mine in Raleigh County, W. Va. Propagation was not obtained in test 205, whereas it was obtained in test 648. This is an important difference, as the result of this early test of Beckley coal was used in determining the position of the explosibility curves for coals of this composition, and it was in conflict with the result obtained with coal dust from the Upper Freeport bed, Indiana County, Pa. (Bulletin 167, p. 306), whose composition differed but little from that of the Beckley coal dust. The new results agree with those obtained from the Upper Freeport coal dust, and revision of the explosibility curves is necessary. This will be explained in succeeding paragraphs.

TABLE 40.—*Results of standard tests of coal dust from the Beckley or War Creek bed, McDowell County, W. Va.*

IGNITION TESTS WITH 20-MESH, 20 PER CENT 200-MESH, DUST

Test No.	Date	Ratio of coal dust to shale dust in mixture	Mixed dust: Calculated incombustible content, per cent	Mixed dust: Rate of loading, pounds per foot	Mixed dust: Total loading, pounds	Natural gas used, per cent	Records obtained in entry or air course	Maximum pressure, pounds per square inch: Station 1150	Maximum pressure, pounds per square inch: Station 950	Time of tin-foil rupture at station E 1250, second	Flame velocity between stations, feet per second: Station 1250 to station 1150	Flame velocity between stations, feet per second: Station 1150 to station 1050	Flame velocity between stations, feet per second: Station 1050 to station 950	Length of flame measured from cannon, feet	Remarks
641	Dec. 15, 1924	80:20	29.2	1.25	937.5	0.0	Entry	1	1	0.888				50	Ignition not obtained.
							Air course	1	1					75	
642	Dec. 16, 1924	(1)	11.5	1.00	750	.0	Entry	1	1	.989				75	Do.
							Air course	1	1					75	
643	Dec. 17, 1924	(1)	11.5	1.00	750	1.0	Entry	11	11	.677	184	198	714	(2)	Ignition obtained.
							Air course	10	13			256		(2)	

PROPAGATION TESTS WITH 20-MESH, 20 PER CENT 200-MESH, DUST

Test No.	Date	Ratio of coal dust to shale dust in mixture	Mixed dust: Calculated incombustible content, per cent	Mixed dust: Rate of loading, pounds per foot	Mixed dust: Total loading, pounds	Natural gas used, per cent	Records obtained in entry or air course	Maximum pressure, pounds per square inch: Station 1150	Maximum pressure, pounds per square inch: Station 950	Time of tin-foil rupture at station E 1250, second	Flame velocity between stations, feet per second: Station 1250 to station 1150	Flame velocity between stations, feet per second: Station 1150 to station 1050	Flame velocity between stations, feet per second: Station 1050 to station 950	Length of flame measured from cannon, feet	Remarks
647	Dec. 26, 1924	80:20	29.2	1.25	812.5	0.0	Entry	4	5	0.213	139	264	82	(2)	Propagation obtained.
							Air course		5				[3] 293	(2)	
712	May 7, 1925	70:30	38.1	1.43	928.5	.0	Entry	3	2	.237	170		[4] 95	(2)	Do.
							Air course	2	2				[3] 297	(2)	
713	May 8, 1925	60:40	46.9	1.67	1,083	.0	Entry	1	1	.167				125	Propagation not obtained.
							Air course	1	1					125	
644	Dec. 18, 1924	80:20	29.2	1.25	812.5	1.0	Entry	15	11			393	535	(2)	Propagation obtained.
							Air course	17	23			356	1,299	(2)	
645	Dec. 19, 1924	70:30	38.1	1.43	928.5	1.0	Entry	12	11	.232	258	277	1,563	(2)	Do.
							Air course	14	17			303	952	(2)	
646	Dec. 22, 1924	60:40	46.9	1.67	1,083	1.1	Entry	6	5			238	124	(2)	Do.
							Air course	6	5			238	503	(2)	
649	Dec. 30, 1924	50:50	55.8	2.00	1,300	1.0	Entry	3	3	.207	173	120		300	Propagation obtained in air course but not in entry.
							Air course	4	3			86	111	(2)	

PROPAGATION TESTS WITH PULVERIZED, 89 PER CENT 200-MESH, DUST

648	Dec. 29, 1924	50:50	55.5	2.00	1,300	0.0	Entry	5	6	0.277	164	192	549	(2)	Propagation obtained.
							Air course	5	6			189	529	(2)	
650	Jan. 5, 1925	40:60	64.4	2.50	1,625	.0	Entry	1	1	.349	91			150	Propagation not obtained.
							Air course	1	1					200	

[1] All coal.
[2] Through zones.
[3] Velocity from station A 1150 to station A 950.
[4] Velocity from station E 1150 to station E 950.

CONCLUSIONS ON EXPLOSIBILITY OF DUST FROM BECKLEY OR WAR CREEK BED

The tests showed that this dust was difficult to raise in a cloud, but when it was so raised the dust was explosive and an admixture of inert material was necessary to prevent propagation of an explosion in the dust. The amount of inert material required to prevent propagation was 47 per cent in the absence of gas, and 58 per cent with 1 per cent of gas present, for 20-mesh coal of which 20 per cent will pass 200-mesh.

Application to field conditions.—As fire damp was found in the mine from which the sample was taken, it would be advisable to keep at least 55 per cent of inert material in the dust. One road-dust sample contained more than this amount, and the addition of an equal amount of rock dust to all of the road-dust samples would give them more than the desired amount of incombustible material. It is noticeable that rib-dust sample A 4976 was pure coal dust and was also very fine. Such dust on ribs or on timber should be dislodged, and rock dust should be scattered in its place after the coal dust has been removed from the mine. The remaining three rib dusts were more like the road dusts in composition and should receive the same treatment.

ANALYSIS OF RESULTS OF TESTS WITH VARIOUS COALS

The results of the tests presented in this chapter, when taken in conjunction with similar results published in Chapter VI of Bulletin 167, permit close examination of the variation of explosibility shown by different dusts when tested in different sizes by two test methods with and without gas present. An outline of the examination is as follows:

1. Results of propagation tests: (*a*) Tests with pulverized dusts; (*b*) tests with 20-mesh dust, 20 per cent through 200-mesh; (*c*) tests with 20-mesh dust, 40 per cent through 200-mesh; (*d*) tests with 20-mesh dust, 10 per cent through 200-mesh.
2. Results of ignition tests: (*a*) Tests with pulverized dusts; (*b*) tests with 20-mesh dust, 20 per cent through 200-mesh.
3. Application to field conditions.

RESULTS OF PROPAGATION TESTS

Tests of pulverized dust with no gas present.—When the testing of various coals was first started, pulverized dust was used exclusively, as has been stated. After the use of 20-mesh dust was adopted as being more nearly representative of the size of dust found in coal mines, it was customary to make a few additional tests with pulverized dust of each coal, if enough of the sample was left. The explosion tests of pulverized dust show the maximum explosibility of the coal under the range of conditions that has been developed in testing at the experimental mine. It was evident from the results obtained and published in Bulletin 167, page 342 and following, that when coal dust was pulverized, its explosibility depended largely on the volatile matter content. Curves for propagation tests were published in Figure 45, page 342, Bulletin 167. These curves were on a small scale, and it was not possible to show all the points which controlled their location.

In the present series, propagation tests were made with pulverized dusts from five additional coals. With four of these five coals the results were close to what would have been predicted from the curves previously drawn; for the fifth coal a higher explosibility was obtained, making necessary the modification of the curves in Figure 45 of Bulletin 167. Figure 8 has been prepared to show clearly the way in which these curves were obtained. In this figure the original and the revised curve for propagation limits in the absence of gas are shown, together with all the tests made under this condition. The dotted curve is identical with the lower curve of Figure 45 of Bulletin 167, and the solid curve shows the modification necessitated by the results of the tests reported in the present bulletin. The ratio of volatile to total combustible content of each coal is plotted as the abscissa, the dotted vertical lines showing the position of the various coals tested. The amount of incombustible required in the mixture in the various tests is plotted as the ordinate along these vertical lines, the test numbers being given. The lettering of the lines representing the coals is the same as in Table 41. Beginning with the lower ratios the coals grade from anthracite through semianthracite, semibituminous, and bituminous coking to high-volatile noncoking coals.

The revision of the explosibility curve affects seriously only those coals having ratios of volatile to total combustible of 0.35 to 1 or less. The maximum change occurs with coals whose ratios are between 0.18 to 1 and 0.20 to 1; with these the amount of incombustible necessary to prevent propagation is raised about 10 per cent. The new curve has a rather sharp break and the section applying to coals with ratios between 0.10 and 0.20 to 1 must be considered tentative until additional coals of this composition have been tested. It so happens that there are only a few coals of this character in the United States, and these are not now the most important commercially.

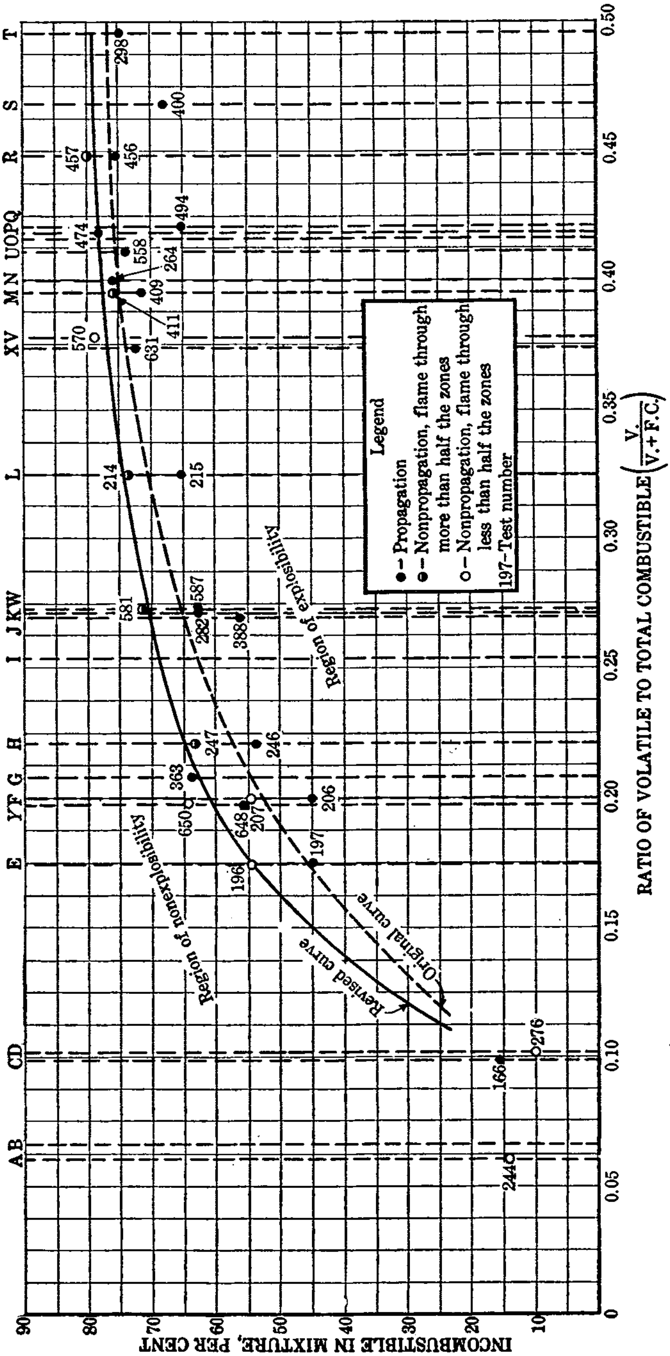

FIGURE 8.—Explosibility curve for propagation tests of pulverized dust, showing effect of volatile matter content in the absence of gas

TABLE 41.—*Explosibility limits for propagation tests with mixtures of pulverized coal dust and pulverized shale dust in the absence of gas*

Index letter	Source or bed	Ratio, $\frac{V}{V+FC}$	Propagation limit, per cent incombustible
A	Wyoming Valley No. 2, Pa., anthracite	0.060	(1)
B	Wyoming Valley No. 1, Pa., anthracite	.066	(1)
D	Bernice, Pa., semianthracite	.102	(1)
C	Lykens Valley, Pa., semianthracite	.099	20
E	Lower Kittanning bed, Cambria County, Pa	.175	48
Y [2]	Beckley bed, McDowell County, W. Va	.198	64
F	Beckley bed, Raleigh County, W. Va	.200	55
G	Upper Freeport or E bed, Cambria County, Pa	.208	65
H	Fire Creek bed, W. Va	.221	60
I	Lower Kittanning, B, or Miller bed, Pa	.254	70
J	Coking coal bed, British Columbia	.270	65
K	Sewell bed, W. Va	.271	70
W [2]	Nickel Plate bed, Jefferson County, Ala	.272	72
L	Upper Freeport or E bed, Indiana County, Pa	.325	73
X [2]	Silkstone bed, Yorkshire, England	.374	77
V [2]	No. 5 bed, Saline County, Ill. (No. 3 sample)	.378	79
M	Keokee bed, eastern Kentucky	.396	76
N	Pittsburgh bed, experimental mine	.400	77
U [2]	No. 5 bed, Saline County, Ill. (No. 1 sample)	.411	79
O	Owl Creek bed, Wyo	.417	73
P	Trinidad coking coal, Colo	.418	82
Q	No. 6 bed, Ill	.420	74
R	No. 4 bed, Mont	.449	79
S	Vancouver Island coal	.468	78
T	No. 5 bed, Ind	.497	78

[1] Propagation not obtained with pure dust.
[2] Tests of this coal described in this bulletin, the others are described in Bulletin 167.

Above the ratio 0.35 the curve was moved up about 3 per cent, so that all tests which gave complete propagation would fall below it. With Pittsburgh dust a mixture containing 76 per cent incombustible (75 per cent shale) was used in six tests, and complete propagation was obtained once. This test (No. 264) has been shown in Figure 8, and the curve as originally drawn fell slightly below it. The coking-coal dust from the Trinidad district, Colorado, was also found to be somewhat more explosive in the two additional tests than the original curve would indicate, and the curve was moved upward in this range because of these two tests. The limit of error in tests at the experimental mine is 3 to 5 per cent, and the change in the position of the curve is not greater than this amount for ratios above 0.35. Further testing is necessary only with coals having a ratio of volatile to total combustible of 0.20 to 1, or less. In this lower region, however, more tests are required before the curve can be properly placed.

Effect of gas on propagation limits of pulverized dust.—Bulletin 167 showed that the presence of gas increased the explosibility. Curves for 1 and 2 per cent of gas were determined in the same manner as the curve with no gas present, and were included in Figure 45 of that bulletin. It has been observed for some time that the increased incombustible content of the dust necessary to offset quantities of gas up to 2 or 3 per cent is, in general terms, directly proportional to the percentage of methane present. Moreover, if the same rate of increase were continued, 100 per cent incombustible would be required at 5 to 5.2 per cent gas. This last figure is approximately the lower explosive limit of pure methane. This observation has led to the thought that the amount of additional incombustible necessary to offset the presence of a given percentage of gas can be obtained more easily by the mining man from a simple rule of behavior and a short table of computed values than from a figure containing curves for 1 and 2 per cent gas.

The rule may be stated as follows: The increase in incombustible in coal-dust and rock-dust mixtures necessary to prevent propagation when gas is present is such that 100 per cent incombustible is required when 5 per cent gas is present. The lower explosive limit of methane or natural gas has never been determined in the presence of incombustible dust clouds, and the figure 5 per cent is taken arbitrarily as the integer nearest to the value indicated by a straight-line extension of the values obtained for 1, 2, and 3 per cent gas. As the rule itself will have no practical application outside this same range—that is, over 3 per cent gas—it is considered satisfactory for use in commercial mines. The amount of incombustible necessary to prevent propagation in the absence of gas varies with the composition of the coal, as shown in Figure 8, which is, as before stated, for pulverized dust only. The additional amount of incombustible necessary to offset 1 per cent of gas is also a variable quantity, as 100 per cent incombustible is reached with 5 per cent of gas irrespective of the composition of the coal. However, the values within close limits are readily computed, and are given in Table 42.

TABLE 42.—*Computed percentage of incombustible necessary in mixtures of various pulverized coal dusts to prevent propagation with and without gas present*

Ratio of volatile to total combustible in coal	Percentage of incombustible necessary to prevent propagation in an atmosphere with—			
	No gas	1 per cent gas	2 per cent gas	3 per cent gas
0.20	62	70	77	85
.25	68	74	81	87
.30	73	78	84	89
.35	76	81	86	90
.40	77	82	86	91
.45	78	82	87	91
.50	79	83	87	92

All the percentages of incombustible in Table 42 depend on those given for no gas in the atmosphere. These in turn are taken from the revised curve of Figure 8 and are consequently no more accurate than the curve itself. That section of the curve from the ratio 0.20 to the ratio 0.50 is well established and is considered to be correct within 3 per cent. Below the ratio 0.20 the error may be larger. The upper section is the more important, as a large majority of the coals fall within it.

From the computed values given in Table 42 it is possible to figure the amount of incombustible material that must be present in a given road dust of the specified size in order to prevent propagation of an explosion with no fire damp or with varying amounts of fire damp present, provided the ratio of volatile to total combustible content is known. For example, let us suppose that the coal of the mine in question has a ratio of volatile to total combustible content of 0.35 and that the dust in the mine is all of pulverized size (such as timber and rib dust might be in a given zone), and contains 50 per cent of incombustible. Then the incombustible content of the dust would have to be raised to 76 per cent to render it inert, or if there were normally 1 per cent of fire damp in the air current, the incombustible content would have to be raised to 81 per cent.

The accuracy of Table 42 can be checked by comparison with the results of 16 explosion tests of 9 different coals. In all of these 16 tests the incombustible content of the dust mixture, as determined by analysis, was less than or equal to that indicated by the table as necessary to prevent propagation. In 7 tests the deficiency was 2 per cent or less. The result in each of these 7 tests was nonpropagation. Also propagation was not obtained in another test in which the incombustible content was as much as 4 per cent below the value computed as necessary. Propagation was obtained in 5 other tests in which the actual content was 3 to 6 per cent below the computed limit. Propagation was also obtained in 3 tests where the incombustible was deficient by 10 to 17 per cent. In other words, based on these 16 tests, the computed values of incombustible given in Table 42 have a margin of safety of 2 or 3 per cent.

The effect of gas was shown in Bulletin 167 by additional curves of the type of Figure 8 of this bulletin (see Bulletin 167, fig. 45, p. 342). As these curves have been found both instructive and useful, they are revised and reproduced as Figure 9 here. The lines indicating the coals and the symbols denoting the tests have been omitted to prevent confusion.

The effect of gas on the explosibility of pulverized dust of a single coal can be well illustrated by a diagram, but it can be better shown in connection with tests of 20-mesh dust because there have been a larger number of tests.

Tests with 20-mesh, 20 per cent 200-mesh, dust.—The results with different pulverized dusts have a fairly regular relation, as Figure 8 shows. Pulverized dust, however, is not the average of that found in the mine; and 20-mesh dust, 20 per cent of which will pass 200-mesh, is more nearly representative, as has been previously

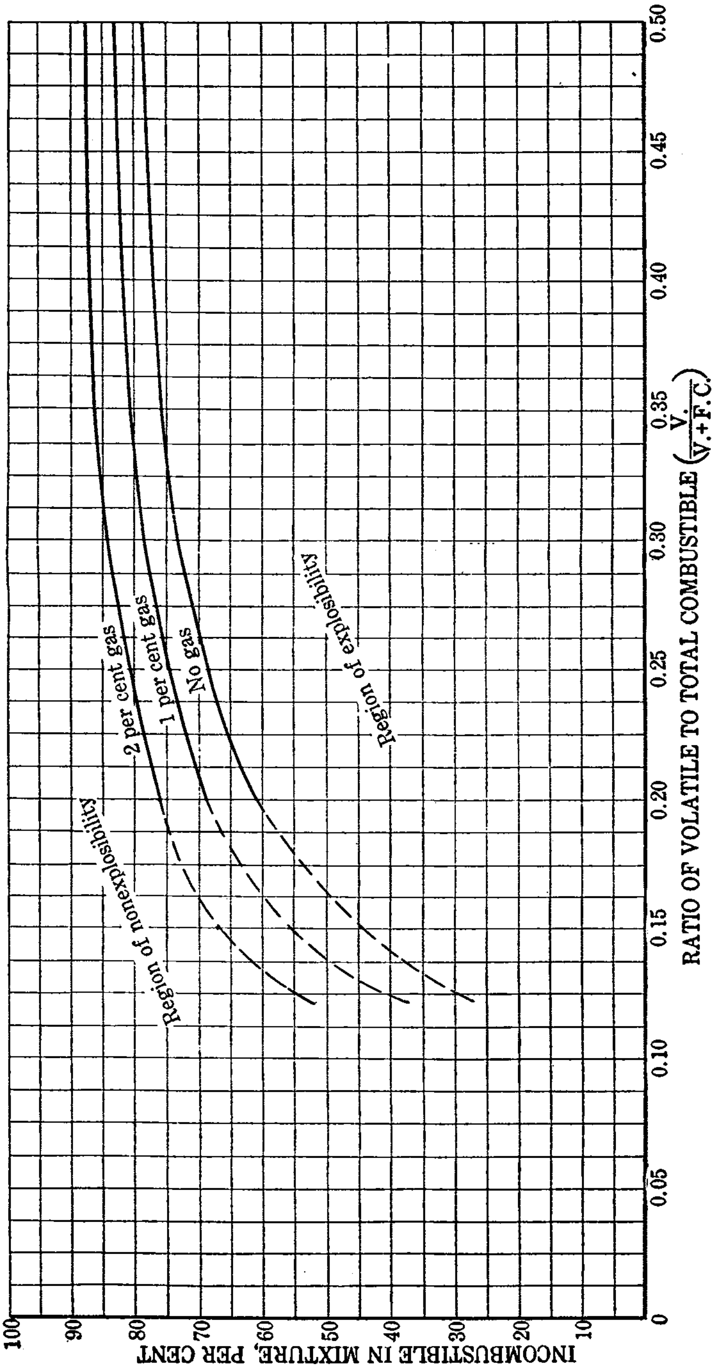

FIGURE 9.—Limiting curve for propagation tests of pulverized dust without and with gas

discussed. Nineteen coals have been tested with this size of dust, and the ratios of volatile to total combustible content for these coals ranged from 0.198 to 0.467, with gaps from 0.20 to 0.25, and 0.27 to 0.37, in which none of the coals tested fell. The tests made of these coals in the absence of gas have been plotted in Figure 10, which is an explosibility curve for 20-mesh dust, 20 per cent through 200-mesh, and is drawn similar to Figure 8 for pulverized dust. The lettered

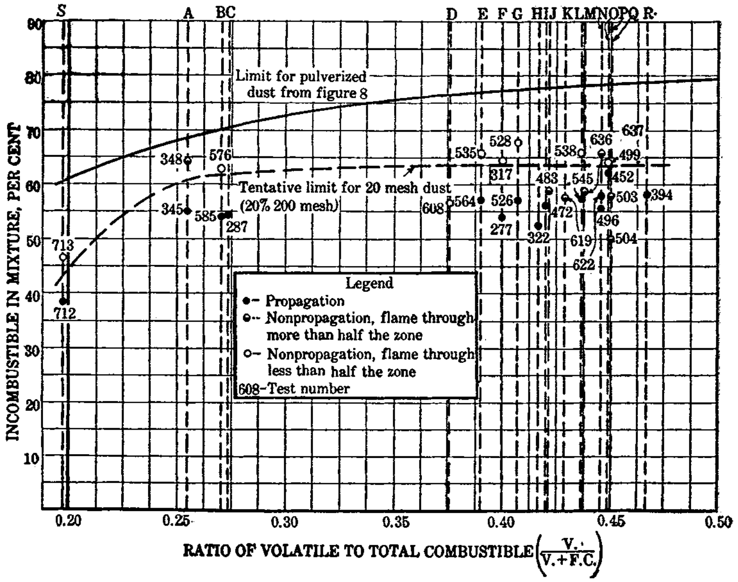

FIGURE 10.—Explosibility curve for 20-mesh dust of which 20 per cent passed 200-mesh, without gas in the air current. Solid curve, limit for pulverized dust from Figure 8; broken curve, tentative limit for 20-mesh dust (20 per cent 200-mesh)

vertical lines represent the various coals, listed according to their ratio of volatile to total combustible material. The various tests are placed on these lines according to the amount of incombustible material in the mixture, and their numbers are given. A solid symbol indicates that propagation was obtained. A half-solid symbol indicates that propagation was not obtained, but that the flame extended through more than half of the mixed-dust zone. An open symbol indicates that propagation was not obtained and the flame extended through less than half of the mixed-dust zone.

The coals represented by the lettered lines of Figure 10 and their source are given in Table 43:

TABLE 43.—*Coals that have been tested with 20-mesh, 20 per cent 200-mesh, dust*

Index letter	Name and source
S [1]	Beckley bed, McDowell County, W. Va.
A	Lower Kittanning bed, Clearfield County, Pa.
B [1]	Nickel Plate bed, Jefferson County, Ala.
C	Sewell bed, Fayette County, W. Va.
D [1]	Jagger bed, Walker County, Ala.
E [1]	No. 5 bed (sample 3), Saline County, Ill.
F	Pittsburgh bed, experimental mine.
G [1]	No. 5 bed (sample 2), Saline County, Ill.
H	Subbituminous bed, Hot Springs County, Wyo.
I	Trinidad coking coal bed, Las Animas County, Colo.
J	No. 6 bed, Franklin County, Ill.
K [1]	No. 9 bed, Union County, Ky.
L [1]	No. 5 bed (sample 1), Saline County, Ill.
M [1]	No. 1 bed, Sweetwater County, Wyo.
N [1]	Raton bed, Colfax County, N. Mex.
O [1]	Pinnacle bed, Routt County, Colo.
P	No. 4 bed, Carbon County, Mont.
Q [1]	Wadge bed, Routt County, Colo.
R	Vancouver Island coal, British Columbia, Canada.

[1] Tests of this coal are described in this bulletin; the others are described in Bulletin 167.

Limit of explosibility.—It becomes evident from an inspection of Figure 10 that the 20-mesh dusts do not show the same regularity in explosibility as that exhibited by the pulverized dusts. A tentative limit of explosibility for 20-mesh dusts has been drawn at 63 per cent incombustible. There is a sharp break in the explosibility limit of coals in the neighborhood of ratio 0.25, and the limit drops to 44 per cent for the Beckley bed dust, whose ratio was 0.198. A similar break is shown in the pulverized-dust curve at ratio 0.20; and possibly the break in the 20-mesh curve should be nearer that point than ratio 0.25, a matter which can be determined only by further tests. The curve for pulverized dust has been added for comparison, and the difference in behavior is evident.

The practical conclusion to be drawn from these tests is that 63 per cent incombustible represents an apparent limit of explosibility for this size of dust for all coals whose ratio of volatile matter to total combustible is 0.25 or more. Complete propagation was not obtained in any of the eight tests where the dust had more than 63 per cent of incombustible, and in six of the eight tests the flame extended less than halfway through the test zone. This limit of 63 per cent would give a margin of safety for some dusts, as in the dust from the Jagger bed, since the flame extended less than halfway through zones of this dust having 57 per cent incombustible material in the mixture.

To determine whether the variation in explosibility can be correlated with any change in either proximate or ultimate analysis, the coals, indicated by their index letter only, were regrouped in ascending order of explosibility, as determined by the tests at the experimental mine. The arrangement in this order, with the important factors of the proximate and ultimate analyses, is given in Table 44.

TABLE 44.—*Relative explosibility of coal dusts mixed with shale dust for 20-mesh, 20 per cent 200-mesh, dust, with analyses of the coals tested*

Index letter	Incombustible in limiting mixture	Proximate analysis			B. t. u.	Ultimate analysis			
		Moisture	Ash	Ratio of volatile to total combustible		Oxygen	Hydrogen	Carbon	Sulphur
	Per cent	*Per cent*	*Per cent*			*Per cent*	*Per cent*	*Per cent*	*Per cent*
S	43	1.0	10.5	0.198	13,700	3.9	4.4	78.9	0.7
D	52	3.5	11.2	.375	12,500	12.1	5.2	69.6	.8
Q	57	9.3	6.7	.450	11,500	21.3	5.8	65.3	.4
K	58	2.6	12.6	.428	13,100	7.8	5.3	73.1	3.2
M	59	10.9	6.1	.438	11,200	22.4	5.6	63.9	.8
J	59	8.8	7.8	.421	11,700	17.5	5.3	66.2	.8
B	60	1.3	6.5	.270	14,500	5.2	5.0	82.5	.8
O	61	7.7	4.4	.446	12,200	18.7	5.8	69.4	.4
E	62	6.7	8.2	.390	12,500	13.9	5.3	68.2	2.5
G	62	4.9	9.4	.407	12,300	11.5	5.2	68.8	3.5
C	63	2.4	5.8	.273	14,600	7.3	5.1	82.6	.5
L	63	4.2	10.7	.437	12,100	11.9	4.9	66.4	4.0
A	64	1.5	9.4	.254	13,600	4.7	4.7	76.7	3.1
F	64	1.9	7.0	.400	13,800	9.2	5.4	76.2	1.4
H	64	18.8	3.6	.417	10,700	26.6	5.6	58.6	.7
I	65	1.6	11.2	.420	13,100	9.5	4.9	66.5	.9
R	65	2.9	14.7	.467	12,300	12.6	5.0	69.0	1.0
N	66	2.8	12.5	.446	12,700	8.2	5.4	70.8	.7
P	69	9.8	12.7	.449	10,300	21.4	5.3	59.3	1.0

The explosibility limits for these dusts given in the second column of Table 44 are estimated from the results of the standard tests described in this chapter and in Chapter VI, Bulletin 167. With 14 of the 19 coals tested, enough data are available to permit a close estimate; the limits for these coals are believed to be accurate within 3 per cent, and are high rather than low. The number of tests with the remaining five coals (C, H, I, P, and R) was small, and the error may be 5 or 6 per cent, but the value is probably high or on the safe side.

Effect of constituents on explosibility.—The nitrogen content has been omitted from the ultimate analyses, as it was virtually the same in all of the 19 coals, varying from 1.2 to 1.6 per cent. The hydrogen content was also fairly uniform, ranging from 4.4 to 5.8 per cent in the 19 samples. The table shows that with 20-mesh dust none of the factors increase in a manner similar to the increase in incombustible necessary to prevent propagation. The amount of inherent moisture and ash in the coal bears no relation to the explosibility of 20-mesh dust; neither does the ratio of volatile to total combustible, except coal S, with a ratio of 0.198. It does not appear possible to make any combination of moisture, ash, and volatile ratio which will vary like the explosibility.

The B. t. u. value also bears no relation to explosibility. Thus coal S requires the least shale and has the fourth highest heating value, whereas coal P requires the most shale and has the lowest heating value. The others fall in no definite order. This is not surprising, as the development of an explosion might be expected to depend more on the rate of production of heat in the initiatory flaming rather than on total heat which might be evolved with complete oxidation.

Also, one is forced to conclude that in comparing the relative explosibility of coarse dust, the ultimate analysis gives no more aid than the proximate. The most explosive coal has a high oxygen and low carbon content, and the least explosive is low in oxygen and high in carbon. The order of explosibility is apparently haphazard in so far as chemical composition is concerned, in contrast with the relative explosibility of powdered coal dusts, which as we have seen group themselves in the order of their ratios of volatile to total combustible content. From this it appears that the size of dust particles is a most important factor in the rank of explosibility of various-size dusts of different bituminous and subbituminous coals.[24]

When two samples of coarse dust from coals of approximately the same composition are compared, their explosibility is found to differ widely. For example, consider dust from the Wadge bed, Colorado (index letter Q), with a ratio of 0.450, and dust from Montana No. 4 bed (index letter P), with a ratio of 0.449. Table 44 shows that both dusts as prepared had about the same composition both by proximate and ultimate analysis, except that the ash content of the Wadge coal was 6 per cent less than that of the other coal; also, the Wadge coal was 10 per cent higher in calorific value. Yet the dust from Montana No. 4 coal was much more explosive, as a mixture containing 62 per cent incombustible gave propagation (in test 452), whereas with dust from the Wadge bed a mixture containing 50 per cent incombustible failed to give complete propagation (in test 504), and in a mixture with 58 per cent incombustible (test 503) the flame barely extended halfway through the zones.

Again it would appear that dust from the Jagger bed (index letter D), with a ratio of volatile to total combustible of 0.375, was less explosive than Lower Kittanning dust (index letter A), with a ratio of 0.254.

Explanation of the differences in relative explosibility of the coarse, uniform-size dusts from different coals, given in Table 44, must be sought in other directions, as in one or a combination of the following factors: The structure of the coal, the ease with which the coarser particles break up to form fine dust, the different ratios of surface to mass in different-size particles, and the ease with which the volatile combustible material is liberated from a particle on instantaneous heating.

Therefore, it is important to test more 20-mesh coal dust at the experimental mine, particularly dusts with ratios below 0.37. Coals with ratios between 0.10 and 0.25 should be tested both as 20-mesh dust and pulverized dust, in order to obtain complete data on the

[24] Dust under the bureau definition constitutes any particles which will pass through a 20-mesh sieve.

curves for both sizes of dust. As a simultaneous investigation, further careful study of the size and composition of the dusts of various coals found in commercial mines will be valuable.

Comparison of samples from a single bed.—Although there is no apparent relation in the explosibility limits of coarse dusts from different beds, the explosibility limits of different samples from the same bed are much alike. Illinois No. 5 bed was sampled in three mines, and the samples (designated as Nos. 1, 2, and 3 in the text and by the index letters L, G, and E in fig. 9) were tested separately. Although they differ in ratio of volatile to total combustible and in composition, they gave very similar results in explosibility tests. Kentucky No. 9 bed (index letter K) correlates geologically with Illinois No. 5 bed, so that there were four samples from the one bed. The limits determined for these coals are given in Table 45.

TABLE 45.—*Explosibility limits of samples from Illinois No. 5 and Kentucky No. 9 beds*

Coal	Incombustible required to prevent propagation with—		
	No gas present	1 per cent gas present	2 per cent gas present
Illinois No. 5.	*Per cent*	*Per cent*	*Per cent*
Sample 1	66	75	80
Sample 2	66		
Sample 3	66	75	82
Kentucky No. 9	58	71	

This table shows that the three samples from the Illinois No. 5 bed had the same explosibility, within the limits of error of the testing work including dust sizing, whereas the sample from the Kentucky No. 9 bed was somewhat less explosive. The mines from which Nos. 1 and 2 samples came were 7 miles apart, and the distance from these to the mine where the Kentucky No. 9 sample was taken was about 30 miles. These are air-line distances. However, there is a pronounced geologic fault separating the Illinois and Kentucky fields that may partly explain the different explosibility of the dust from the two fields. On the whole, then, it can be said that a sample from one point in a coal bed will give results that will be representative of a large area in that same bed surrounding the point of sampling, where the bed lies in a single basin and is everywhere subject to the same geologic conditions.

The limit of 66 per cent for Illinois No. 5 coal shown in Table 45 does not in any way invalidate the previous conclusion that 63 per cent incombustible will prevent propagation with coals coming within the range of those tested. It may seem inconsistent to say that 63 per cent incombustible will prevent propagation with coals of the range tested when 66 per cent is given in Table 45 for the Illinois No. 5 samples, but there is this difference: The 66 per cent incombustible given in the table is the content of an arbitrarily selected mixture which in test failed to give propagation with these coals, and it is likely further testing with intermediate mixtures would in all probability reveal that 63 per cent would prevent propagation. When the results of a large number of tests are known and plotted, as in Figure 10, an intermediate curve can be drawn and values taken from this curve can be safely used. The 63 per cent limit is, of course, subject to revision as further test results may indicate. Revision will also be necessary when the exact rule of behavior of 20-mesh dusts is determined.

Effect of gas on explosibility of 20-mesh, 20 per cent 200-mesh, dust.—The explosibility limits of most of the 19 coals tested with 20-mesh, 20 per cent 200-mesh, dust were determined with gas present in the air current in amounts up to 2.4 per cent. There were 38 of these tests, and a study of the results has shown that they agree with the rule of behavior already announced for pulverized dusts, namely, that the rate of increase in incombustible content of the dust required to offset increasing percentages of fire damp in the air is such that dust having approximately 100 per cent of incombustible would be required in an air mixture having 5 per cent of natural gas. In order to examine this relation, the amount of incombustible required for each of the 38 tests was computed, according to the rule, from the "incombustible in limiting mixture" given in Table 44, and the percentage of gas actually present in the test. These computed amounts of incombustible were tabulated, together with the actual amounts present as shown by analysis of the mixed dust, and the result which would have been predicted was compared with the actual or trial test results. It is evident that if the actual percentage of incombustible used was less than that computed to be necessary, the result to be predicted would be "propagation"; also if the actual amount were greater than the computed, "nonpropagation" would be expected.

Results of tests, by classes.—The results of the 38 tests may be divided into three classes: (1) 17 tests in which complete propagation was obtained; (2) 9 tests in which propagation was obtained in the air course but not in the entry, indicating that the mixtures were on the border limit of explosibility; and (3) 12 tests in which propagation was not obtained through either zone.

In all but one of the 17 tests of class 1 the actual percentage of incombustible was less than the computed amount necessary; in the other test both had the same value. The deficiency of "actual" incombustible varied from 1 to 25 per cent in these tests. When the deficiency was 6 per cent or less the explosions were weak and slow. When the deficiency increased above 6 per cent, the flame velocity and pressure of the explosions increased. There were two tests in which the deficiency was more than 15 per cent, and these were rapid and violent. The matter is summarized by saying that in 16 of the 17 tests in which propagation was obtained, the "actual" incombustible content was deficient. When this deficiency was small the explosions were weak and slow. As the deficiency increased, the violence of the explosion increased. The result of one test in which the incombustible content by analysis was equal to the computed amount required, but failed to prevent propagation, has no definite explanation. Whether there was some error in analyses of the dust mixture or of the samples for natural gas, or whether this is a real exception to the rule, can not be said.

The nine tests of class 2 may be considered as being directly on the border line of explosibility, as the flame died out in one of the two parallel paths. The comparison of "actual incombustible content" to "computed incombustible limit" in these tests was as follows: In two tests the actual was in excess by 1 and 2 per cent, in four tests the actual was deficient by 1 or 2 per cent, and in three tests the actual was deficient by 4, 6, and 6 per cent.

In seven of the nine tests the actual incombustible content was deficient on the computed basis, and the result in these seven tests was incomplete propagation. In two of them the deficiency was so great (6 per cent) that complete propagation would have been predicted. One of these exceptions may be explained by the fact that the outer end of the main entry was wet, but there is no adequate explanation for the other exception. However, the errors in fixing the limiting percentage of incombustible that will prevent propagation are all on the side of safety, as the tested mixtures that were deficient in incombustible as compared with the computed limit failed to give propagation.

In 10 of the 12 tests in class 3 (tests which gave nonpropagation) the "actual incombustible content" was more than the "computed content" by 2 to 7 per cent, and in the other two tests was the same as the computed requirement.

Effect of fire damp.—With reference to the effect of the presence of fire damp, the general agreement of the 38 tests with the rule of behavior as formulated (see p. 110) is satisfactory, and nearly all variations which occur can be explained by assuming that the error of determination of "computed" incombustible does not exceed 3 per cent. This error probably lies in the determination of the explosibility limit of dust with no gas present, as this value was interpolated between those for tests in which the amount of shale in the mixed dust was changed by 10 per cent increments. More recently the testing has been carried to the nearest 5 per cent of shale content, but the number of such tests reported in this bulletin is small. The agreement is so satisfactory, however, that this method of testing dusts will be continued, but the procedure will be modified to obtain more precise limits. The limit of explosibility with no gas present will be determined as a value interpolated between two tests differing in shale content by 5 per cent, one of which gives propagation and the other nonpropagation. The content of incombustible necessary to offset 2 per cent of gas will then be computed, and a mixture with this amount will be prepared and tested with that amount of gas.

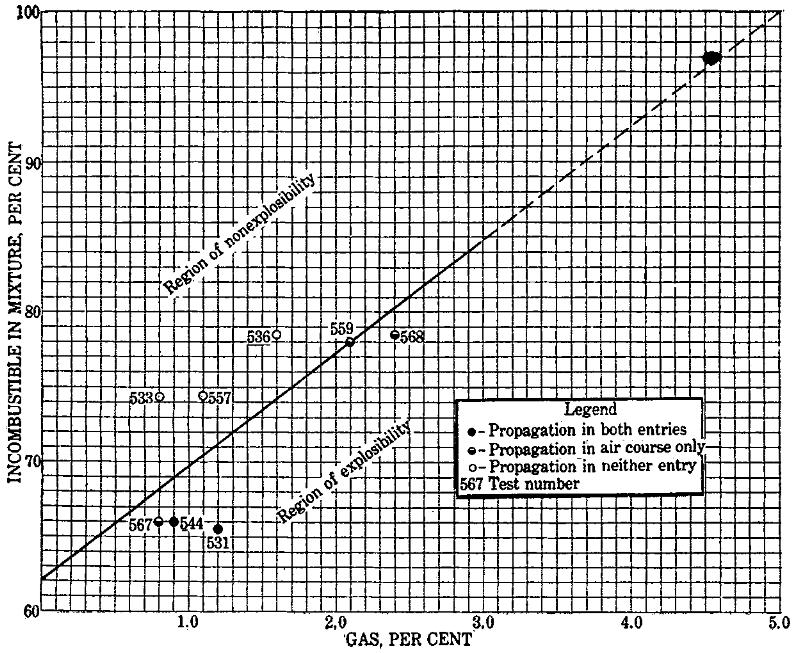

FIGURE 11.—Limiting curve showing effect of small percentage of gas on explosibility of 20-mesh Illinois No. 5 bed dust, having 20 per cent through 200-mesh

If the result agrees with the prediction, it may be concluded that no further tests in which gas is used will be necessary.

It is desirable as a matter of research to run a series of tests with Pittsburgh coal dust in which the gas in the air current is varied from 0 to 3 per cent in steps of about 0.25 per cent, in order to determine accurately whether the increase in incombustible to offset gas is a linear function, as the rule assumes.

The effect of gas is also shown graphically in Figure 11. The 20-mesh dust from coal of the Illinois No. 5 bed (samples E, G, and L, Table 43) is selected as the example in this figure. The three samples all required the same amount of incombustible material in the limiting mixture, and they may be considered as one sample for the present purpose. There were eight tests in which the gas content of the ventilating current ranged from 0.8 to 2.4 per cent, and each test is represented by a symbol in the position determined by the percentage of gas in the air and the percentage of incombustible in the mixed dust. The solid circles for tests 531 and 544 indicate that complete propagation was obtained in these tests. The half open circles of tests 559, 567, and 568 indicate that propagation was obtained in the air course but not in the entry. The open circles of tests 533, 536, and 557 indicate that propagation was not obtained in either entry.

The explosibility limit was set at 62 per cent incombustible with no gas, and a straight line has been drawn from this point to 100 per cent incombustible with 5 per cent gas. The mixtures used in tests 531 and 544, under the conditions of these tests, fall in the "danger" zone, being 6 and 3 per cent, respectively, below the line. Those used in tests 567 and 568 also lie about 2 per cent below the line, while that of test 559 lies directly on the line. These three latter mixtures would be considered unsafe under test conditions, as they are the three tests that gave propagation in the air course but not in the entry. Tests 533, 536, and 557 lie in the "safety" zone, from 3 to 6 per cent above the limiting line, and all three failed to give propagation. The figure illustrates quite clearly the change of explosibility as gas is added to the atmosphere.

It is interesting to note that a 1 per cent gas mixture contains 0.00662 ounce of methane per cubic foot of mixture and a 5 per cent mixture contains 0.0332 ounce at a temperature of 60° F. This is to be compared with 0.08 ounce of pulverized coal dust per cubic foot, calculated from the amount placed on shelves and floor, which was the smallest amount under experimental mine conditions that gave propagation,[25] and with 0.04 ounce, which did not give propagation. The evidence was, however, that only a part of the dust was consumed in the test with 0.08 ounce of dust per cubic foot. In the Pittsburgh explosion gallery 0.032 ounce of pulverized coal dust per cubic foot gave an "ignition"[26] under the conditions of test; thus a unit weight of methane in an explosive mixture is on a comparable basis with the unit weight of pulverized pure coal dust that may propagate an explosion.

Tests of 20-mesh, 40 per cent 200-mesh, dust.—Five of the coals reported in Bulletin 167 were tested with 20-mesh dust, 40 per cent of which would pass through 200-mesh. One additional coal was similarly tested in the present series, this being the sample from No. 5 bed, McKinley County, N. Mex. The conclusions drawn in Bulletin 167 were that this size of dust is only slightly less explosive

[25] Bulletin 167, p. 94.
[26] Bulletin 20, p. 41.

than pulverized dust prepared from the same coal. No tests were made with pulverized dust prepared from the sample of New Mexico No. 5 coal, but the 20-mesh (40 per cent through 200-mesh) dust prepared from this coal had slightly lower explosive limits than would be predicted for pulverized dust from the curve of Figure 8. When this size of dust is found in a mine and precise determinations have not been made, it is best to use the explosibility limits for pulverized dust of the same ratio of volatile to total combustible content. The difference can not represent more than 2 or 3 per cent excess of incombustible material, and this would act as a small factor of safety.

Tests of 20-mesh, 10 per cent 200-mesh, dust.—This size of dust was used in tests of three coals reported in Bulletin 167. As little coal dust of this size is made in mines, it was not used in the present series of tests. The information obtained is too meager to permit conclusions to be drawn, but in behavior it resembled the finer dust of which 20 per cent passed 200-mesh. The explosibility, as might be expected from the results of testing the finer size, was independent of the ratio of volatile to total combustible (which ranged from 21 to 40 per cent in the three coals tested), and the limit was somewhat lower than that of the finer size. A tentative limit of explosibility for this size of dust, to be on the safe side, may be set at 60 per cent incombustible. This is only 3 per cent lower than that set for 20-mesh dust of which 20 per cent passed 200-mesh.

Summary of propagation tests.—The results of the propagation tests may be summarized as follows:

For pulverized dust the limits have been determined accurately enough in the absence of gas and are shown in Figure 8. It is manifestly desirable to run more check tests with coals having ratios of volatile to total combustible content between 0.10 to 1 and 0.20 to 1.

Twenty-mesh dust, of which 20 per cent would pass 200-mesh, has been found in a majority of tests to be the size more nearly representing the dust found in operating mines, but the proper method of sampling the dust in a mine is still a question open to further research. With this size of dust, however, the explosibility of dust tested did not vary with the ratio of volatile to total combustible when this was more than 0.25 to 1, as did the explosibility of the same dusts when pulverized. Sixty-three per cent incombustible present in a dust mixture of which 20 per cent would pass through 200-mesh would prevent propagation of an explosion in the absence of gas in mixtures of any of the 19 coals tested, irrespective of the composition of the dust determined by proximate or ultimate analysis. However, one or two of the coals were less explosive than this limit would indicate. Different samples from a single coal bed taken within a range of 7 miles showed nearly the same explosibility. The presence of fire damp in the atmosphere increased the explosibility of the dust, as previously reported in Bulletin 167, and additional incombustible material was necessary to prevent propagation of an explosion. For practical purposes it may be considered that the incombustible increased at such a rate that 100 per cent total incombustible would be necessary to prevent propagation when 5 per cent of gas is present.

Twenty-mesh dust, of which 40 per cent passed through 200-mesh, was only slightly less explosive than pulverized dust. Twenty-mesh dust, of which 10 per cent passed through 200-mesh, was tested for three coals only, but a tentative limit of 60 per cent incombustible in the absence of gas may be set for it. However, it is safer to consider that in any mine the dust may in certain parts have at least 20 per cent passing through 200-mesh, and protective measures should be taken accordingly. Judging from the mine sampling so far done in different parts of the country, it is so exceptional to find dust with only 10 per cent through 200-mesh that except for special testing no further intensive studies of this size are anticipated.

RESULTS OF IGNITION TESTS

Tests with pulverized dust.—The ignition test is less severe than the propagation test, and the percentage of incombustible required to prevent ignition is always less than that required to prevent propagation. Also, when a mixture gives "nonignition" under the conditions of standard testing, the flame rarely extends through as much as one-half and often not more than one-third of the test zone.

The ignition tests of pulverized dusts show a variation of explosibility with volatile content of the coal in the same manner as the propagation tests. A curve for these ignition tests in the absence of gas is shown in Figure 12. The similarity to the curve (fig. 8) for the propagation tests will be readily noted. The main difference is that the ignition tests indicate a lower explosibility of the dust. Comparison of the values indicated by the curves for the ignition and propagation tests with no gas present is made in Table 46.

TABLE 46.—*Comparison of explosibility limits of pulverized dusts in ignition and propagation tests, as indicated by percentages of incombustible required, with no gas present in the ventilating current*

Ratio of volatile to total combustible in coal	Explosibility limits, incombustible in mixture		Difference
	Ignition	Propagation	
	Per cent	*Per cent*	
0.20	43	61	18
.25	53	68	15
.30	57	73	16
.35	60	76	16
.40	62	77	15
.45	62	78	16
.50	63	79	16

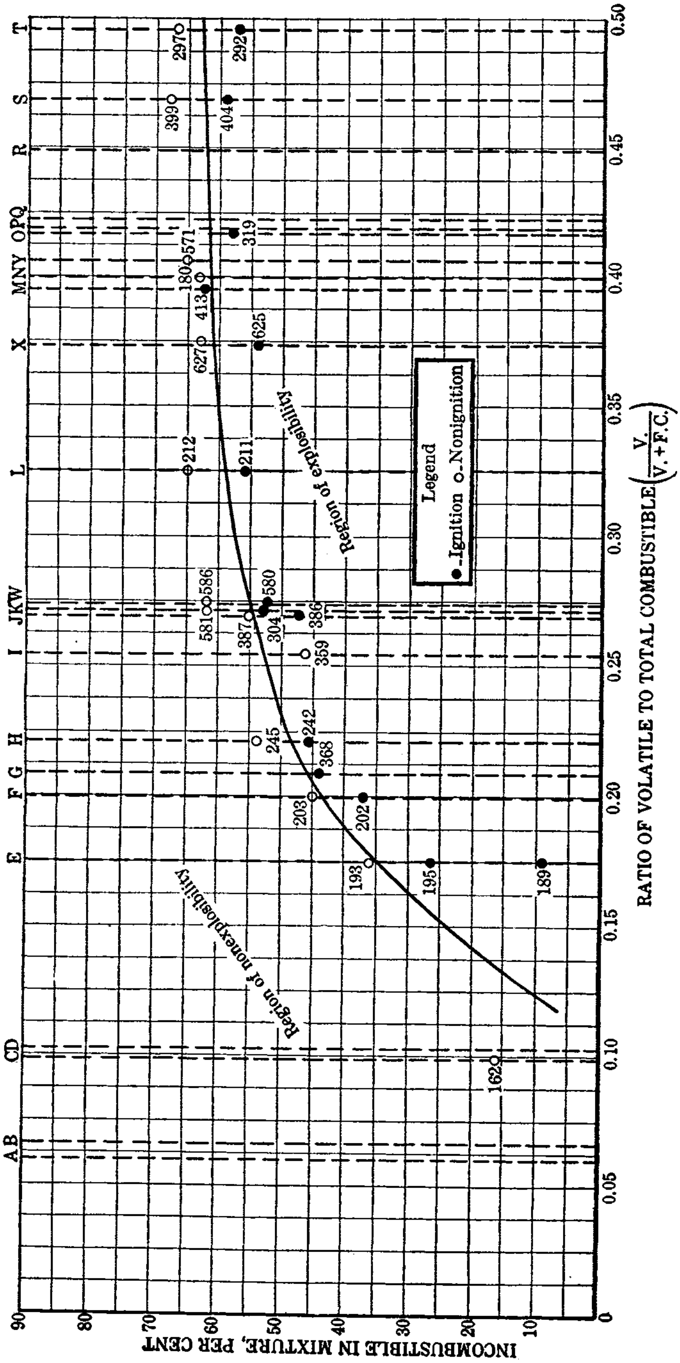

FIGURE 12.—Explosibility curve for ignition tests of pulverized dusts, showing effect of volatile matter content in the absence of gas

As a general average, it may be said that in the absence of gas the incombustible content required in a mixture of pulverized dust to prevent ignition is 16 per cent less than is required to prevent propagation. This points to the importance of preventing ignition.

Fire damp increases the explosibility of dust in ignition tests as in propagation tests. Additional incombustible must be present to offset the gas, and the increase is at such a rate that practically 100 per cent incombustible would be required with 5 per cent gas. Thirty ignition tests were made with pulverized dust in the presence of gas. The incombustible content necessary to prevent ignition was computed for these tests, tabulated with the actual incombustible content present in the mixtures used, and the predicted result compared with the actual result. The 30 tests may be divided into two classes: (1) 16 tests which gave ignition and (2) 14 tests which gave nonignition.

In 14 of the 16 tests which gave ignition the actual incombustible present, as compared with the computed limit, was deficient by 4 to 25 per cent. The deficiency in six tests was 9 per cent or more and the explosions in these tests were rapid and violent. The speed and violence increased as the deficiency increased. When the deficiency was 25 per cent, the flame velocity reached 3,000 feet per second, the pressure exceeded 65 pounds per square inch, and one of the manometers was wrecked.

In the two remaining tests which gave ignition, the actual incombustible content was, respectively, 1 per cent deficient and 1 per cent in excess of the computed limit. These explosions were slow and the pressures were moderate. It is evident that the two mixtures were close to the limit of explosibility, and that for these coal dusts the computed limits were too low.

In 7 of the 14 tests which gave nonignition, the actual incombustible content exceeded the computed limit by 1 to 7 per cent. In five of the seven remaining tests, the combustible content was deficient by 1 to 4 per cent, and in the two final tests by 6 per cent. This indicates an error on the side of safety, as it would be predicted that ignition would occur when the actual incombustible was deficient. To summarize, predictions based on the calculated incombustible limit would have been either correct or in error on the side of safety in 28 of the 30 tests. It must be noted that the ignition limit with no gas present was not determined as closely as the propagation limit—that is, the spread in percentage of incombustible was greater than in the tests for determining the propagation limit, and the error of determination may be as much as 5 per cent in certain tests.

The effect of fire damp in ignition tests can be shown graphically in the same manner as in propagation tests. Figure 13 shows the limiting curves for ignition tests without and with gas present. The

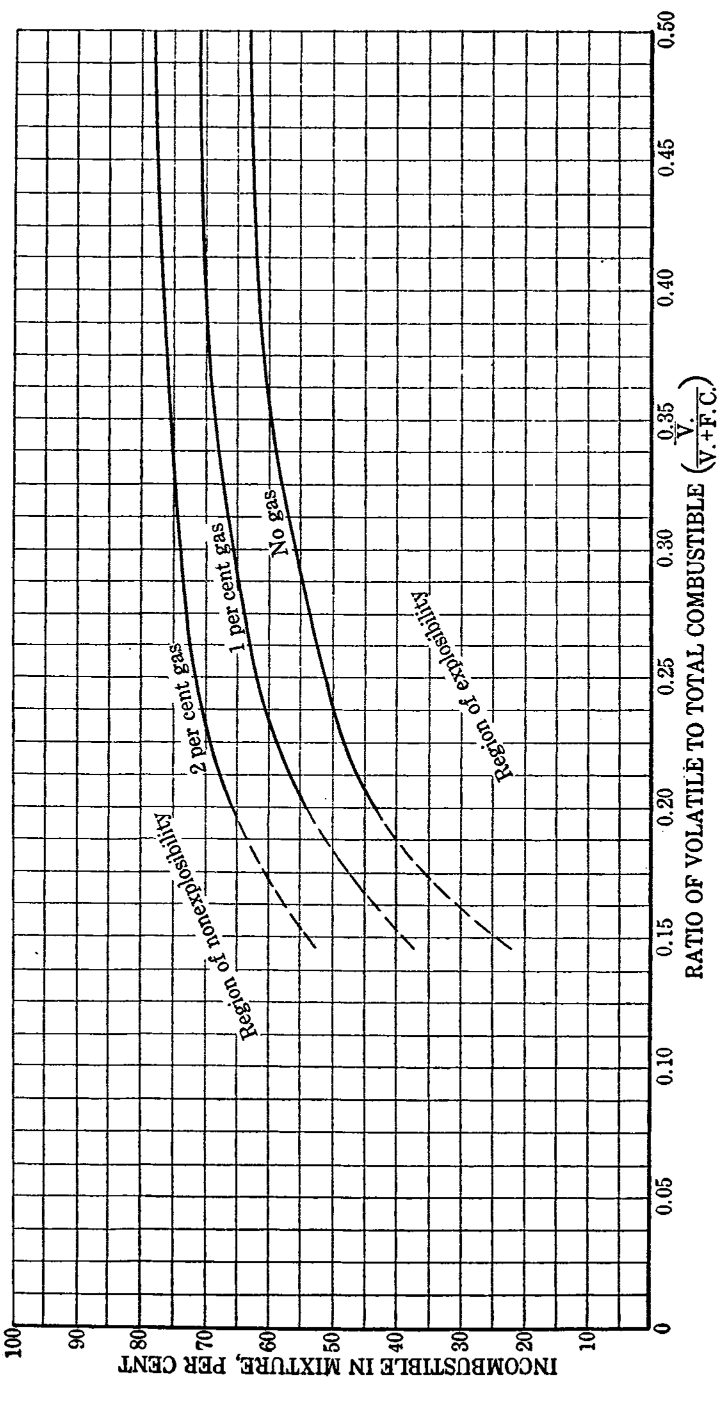

FIGURE 13.—Explosibility curve for ignition tests of pulverized dust, showing effect of volatile matter content without and with gas

curve for no gas is the same one shown as Figure 12. The test points have been omitted from Figure 13 to avoid confusion.

Tests with 20-mesh, 20 per cent 200-mesh, dust.—The irregularity that characterizes the propagation limits with 20-mesh dust is even more pronounced for the ignition limits. There is a certain percentage of incombustible above which ignition did not take place in any dust mixture tested, but there are several coals that failed to give ignition with 10 to 15 per cent less than this amount of incombustible in the mixture, and in one test ignition was not obtained with pure coal dust in the absence of gas. This was with Beckley bed dust (coal S of Tables 43 and 44) which had a ratio of volatile to total combustible of 0.198. On the other hand, in test 349 with 20-mesh, 20 per cent through 200-mesh, Pittsburgh coal dust, a mixture containing 45 per cent incombustible gave ignition with no gas present. This mixture is the only one that gave ignition with more than 40 per cent incombustible present. It is evidently close to the dividing line, as ignition was not obtained in test 328 with a similar mixture. The fact that the experimental mine was somewhat damp at the time of test 328 may have had some effect on the result. Considerable additional work will be necessary before these variable results can be correlated. Varying the strength of the igniting source may disclose information of value.

The effect of fire damp in ignition tests agrees roughly with the rule that in order to prevent an explosion the incombustible content of the dust must increase at such a rate that practically 100 per cent incombustible would be required with 5 per cent gas. The number of ignition tests in gas was somewhat limited; furthermore, the ignition limits of the dusts with no gas present were not determined as closely as the corresponding propagation limits. There is also the possibility that a different behavior may be encountered in ignition tests. Additional work must be done before a definite statement concerning the action of gas in ignition tests with coarse dust can be made.

APPLICATION TO FIELD CONDITIONS

Mining men in the United States are in general acknowledging that rock dusting is the best means for rendering coal dust inert in dry mines. The principal questions now under discussion concern the method of application, the kind and size of dust that should be used, the amount that should be used, and the maximum amount of combustible material that will be permitted before the zone is again rock dusted.

Principles of rock dusting.—Tentative specifications [27] have been issued by the Bureau of Mines. In these it is stated that the com-

[27] Rice, G. S., Paul, J. W., and Sayers, R. R., Tentative Specifications for Rock Dusting to Prevent Coal-Dust Explosions in Mines: Repts. of Investigations Serial 2606, Bureau of Mines, May, 1924, 6 pp.

bustible content of the mine dust must not exceed 45 per cent with no gas present. This is equivalent to saying that after a mine has been rock-dusted, whenever the incombustible content of the dust falls below 55 per cent in any part of the mine, that part should be rock-dusted again. It was anticipated that the average incombustible content of the dust throughout a mine would then be 15 to 20 per cent higher than the minimum. Also, 5 to 10 per cent additional rock dust should be used for each 1 per cent of gas present; and all entries, slopes or passageways, and room necks should be rock-dusted.

If the results of the propagation tests on the various coals reported in this chapter are taken as a standard, it may seem that the minimum limit set (55 per cent incombustible) is too low and will not produce safe conditions. It must be emphasized, however, that the minimum requirement of the specifications refers to any one point in a mine, and where such a condition is found, rock dust should again be applied. Practically it was expected (and the results have verified the expectation) that elsewhere in the mine the average incombustible content of the mine dust is much higher than 55 per cent. In any case, the application of test results to conditions in an operating mine must be made with some caution, and one point to remember in this connection is that the explosibility of coal dust is a variable quantity.

The most important fact, in any one operating mine, is that the explosibility in the initiatory stage varies with the strength of the source of ignition. In other words, less rock dust is necessary in the mixture to prevent the spread of an explosion when the source of ignition is weak. Thus, with the propagation test an explosion of considerable power develops in the pure coal dust near the face, and there must be 63 per cent incombustible in the mixed dust to prevent the continued spread of this initial explosion. But when a blown-out shot of 4 pounds of black blasting powder is fired directly into the mixed dust under test, the amount of incombustible required to prevent "ignition" of an explosion is reduced to approximately 46 per cent. The tests of coal dust from the Silkstone bed showed that if less than this amount of powder was used, the amount of incombustible required was again reduced. However, there are practical considerations which make it advisable to continue the use of an initiatory source not weaker than the impulse from 4 pounds of black blasting powder. For example, the ignition at the face of a 50-foot zone of fire damp of maximum explosive proportions will give a starting effect much stronger than that of a blown-out shot of 4 pounds of powder.

The second principal factor is the greater difficulty of initiating and sustaining an explosion in a working room, or in an entry in which the face is only a short distance in advance of working rooms, as compared to entries where there are no side openings for a considerable distance from the face. Tests proving this are given in Chapter VII of Bulletin 167 and later in the present bulletin.

The important question is evidently not what was the result of a certain test in the experimental mine, but what are the actual conditions in the operating mines of the country which are to be made safe. What is the maximum condition of explosibility that will be found in these mines?

Initiation of explosions.—Most explosions start at or near some working face. The principal exception to this is the starting of an explosion in a dense cloud of dust by an electric arc. This may occur on any haulage entry where trolley haulage is used, and a derailment and wreck resulting in a short circuit of the electric system occurs simultaneously with the production of a dense dust cloud of pure coal dust from the wrecked cars and mixed dust from demolished timbering. It is impossible to predict how much coal dust may thus be put into suspension, but if there is ample rock dust along the haulageway any incipient explosion will rapidly die away. It is especially important, however, to remember that the majority of explosions start near the faces.

For the present discussion, a mine can be assumed in which rock dusting has been carried into the rooms and through the last cut-throughs connecting the entries, and the general rock dusting is supported by rock-dust barriers of approved type at critical points, such as the entrances to panels or separate divisions of a mine. It may be immediately stated that rock dusting is of little value in a mine which gives off fire damp in appreciable amounts, unless it is accompanied by adequate ventilation. If an explosive mixture of gas accumulates, only a spark is needed to initiate an extensive gas explosion, which is the most violent source of ignition for coal dust that is met with in operating mines. Rock dust can not prevent gas explosions where there is an explosive mixture. It is not known whether rock dust has any effect on propagation of a gas explosion by its heat-absorbing effect, but the effect is undoubtedly small. In any case the gas is already in the air, whereas the rock dust is on the ribs, roof, timber, and floor with the coal dust it is intended to neutralize, and it takes time for either to rise into the air.

Assuming that ventilation is properly maintained, attention may be directed to entries which have the faces well in advance of rooms or of other entries turned from them. Under ordinary conditions there will be a length of entry between the last cut-through and the face that is not rock-dusted and which contains dry coal dust that may be directly ignited by a blown-out shot of black blasting powder or dynamite; and if fire damp is given off, a blown-out or overcharged shot of a permissible explosive (thus used in a nonpermissible manner) may be the cause of an ignition. It is evidently important to use permissible explosives in a permissible manner for all shots in coal mines. In headings and rooms it is desirable to use water sprays on the cutter bars of mining machines, and to wet down the face and its vicinity by hose as is now practiced in a number of States and required by the regulations of one State.

SUMMARY OF SAFETY PRECAUTIONS

This analysis could be carried much further, but the principle of rock dusting involved is summed up as follows:

Keeping a minimum of 55 per cent of inert material in every part of the mine dust will render it safe from the ignition hazards normally met. To be sure that there may be no source of ignition sufficiently violent to start an explosion in this dust, the ventilation must be carefully maintained, especially at the face, and permissible explosives employed exclusively for blasting. Additional precautions, such as the use of closed lights and explosion-proof mining machinery, are also most important. These are primarily to prevent ignition of accumulations of gas which may come from encountering gas blowers or from damage to doors and brattices through accidents. Entire safety is found only in a well-balanced effort to meet all the contingencies that may arise.

In further reference to the tentative specification requirement of a minimum of 55 per cent of incombustible, it was not intended to convey the idea that 55 per cent was enough, but rather that when the incombustible content of the dust in any part of the mine fell to or below that figure, such area of the mine would be redusted. Practical conditions were taken into account, and it was the expectation from the experience obtained in 5 years' general use in Great Britain with a requirement of only 50 per cent incombustible, that if redusting is required when any section of a mine in this country shows less than 55 per cent of incombustible, the general average for the mine will be about 70 per cent of incombustible.

TESTS WITH EXPLOSIONS ORIGINATING IN ROOM ENTRIES

The question of the behavior of explosions originating in entries off which rooms are turned was early recognized as important, and three tests with pure coal dust were made in 1914. Additional tests with mixed dust were made in 1917 and 1918. All of these were reported in Chapter VII, Bulletin 167, beginning on page 363.

The Pittsburgh coal bed has strongly marked parallel cleats or faces. Rooms are laid out to advance directly on or at right angles to the faces. The entries off which the rooms are turned advance on the coal "ends" or "butts," and are known in the Pittsburgh district as "butt entries," but the term is not in universal use in this country.

The room entries in the experimental mine are now designated as first left and second left. However, the Pittsburgh district term had first been applied and is still used in symbols. Thus, a point in No. 1 left entry 400 feet from its mouth would be designated by the symbol 1 B 400.

In the tests reported in Bulletin 167, the left entries of the experimental mine were only 350 feet long. In 1914 there were four rooms turned off No. 1 left, varying in length from 50 to 100 feet, whereas in 1918 No. 5 room had been turned and all five rooms were 150 to 200 feet long (see fig. 1).

The tests made in 1914 did not develop high pressures in No. 2 left entry. It was thought that the explanation would be found in the fact that No. 2 left entry squarely faced the solid wall of the air course and pressure waves reflected from this wall might tend to retard the advancing explosion (see Bull. 167, p. 368).

The tests in 1917 and 1918 were made with mixed dust to determine the effect of weak and strong stoppings on the development of an explosion. These tests were not conclusive, but it again became evident that there was a considerable difference between results obtained in the main entries and in the left entries, a given dust appearing to be less explosive in the left entries as they were then arranged.

It was evidently necessary to extend the left entries and observe the effect of changed length before any conclusions could be drawn. Accordingly arrangements were made to drive both left entries to their present length, a distance of 525 feet from the air course. This work and the work of installing instrument stations and cable was completed in the fall of 1920, and a series of 20 tests was made in the winter of 1920–21.

DESCRIPTION OF LEFT ENTRIES

Figure 14 is a plan of the experimental mine, showing the development of the left entries and rooms when the tests described in this bulletin were made. The left entries were 525 feet long, measured from the center line of the air course. Cut-throughs connected them at points 100, 200, 300, 400, and 475 feet from the air course. This placed the faces of the left entries 50 feet ahead of the last cut-through, the distance being the same as in the main entries, and as it had been in the early tests in the left entries. The 100 cut-through had a heavy concrete stopping in it. The other cut-throughs had no permanent stoppings, and were either left open or were closed by temporary stoppings, as was desired in the test. Beyond the 400 cut-through on the left entry the coal bed dips downward at a low angle toward the face, and some small clay veins and water were encountered in mining. Moreover, the draw slate over the coal in No. 1 left entry became very thick, being 4 feet at one place.

As the draw slate is taken down with the coal, this made the roof much higher than in other parts of the mine. It was found necessary to blast a sump in the floor about 25 feet from the face of No. 1 left to hold the accumulated water. The track was carried over the sump on 8 by 8 inch timbers, and a board cover was placed on the ties.

Six rooms varying in length from 185 to 210 feet were turned off No. 1 left. Cut-throughs connected the rooms at points 30 and 135 feet from the entry, except between Nos. 1 and 2 rooms, where the second cut-through was 85 feet from the entry and there was a third near the face.

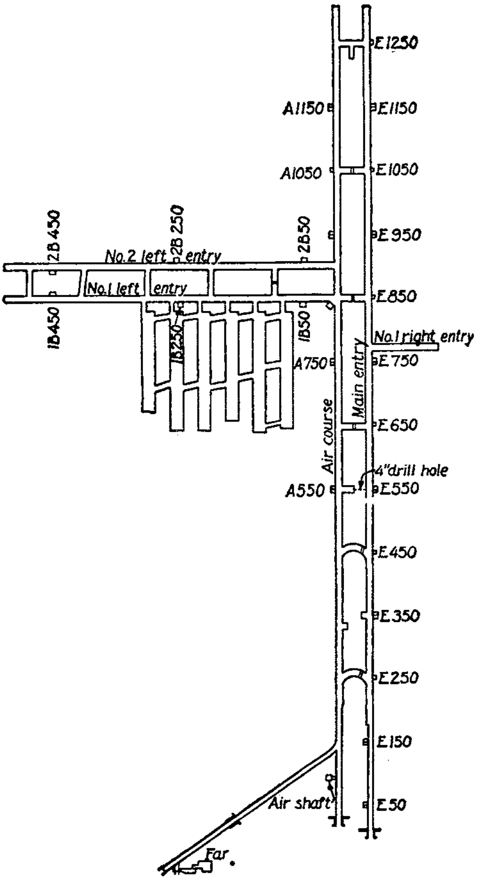

FIGURE 14.—Development of experimental mine in 1920, when tests were made in the left entries

There were large instrument stations in both left entries, at points 50, 250, and 450 feet from the air course, and there were also tin-foil stations midway between the large stations. Complete records could thus be obtained, as in the main entry.

PURPOSE OF TESTS

A general outline of the proposed work was drawn up and provided for three major divisions, as follows:

1. Tests to determine the effect of changing the length of the left entries.
2. Tests to determine the effect of weak and strong stoppings on the development of an explosion.
3. Tests to determine the effect of position, direction, quantity of charge, and kind of tamping of a blown-out shot on the initiation of an explosion in rooms.

Under division 1 it was proposed to duplicate certain earlier tests and observe the results. The effects of the position of the igniting shot (face of No. 1 left or No. 2 left) and variation in the mixture and the length of the mixed dust zone were to be determined. Under division 2 it was proposed to determine the effect of no stoppings, weak stoppings, and strong stoppings in the 200, 300, and 400 cut-throughs on the development of an explosion. The 475 cut-through was to be always open, as the last cut-through in a producing mine must be used for ventilation. The work under division 3 was to be carried out in a room and was intended to determine the conditions under which direct ignition of coal dust would take place.

Fourteen tests were made under division 1 and gave the information sought. Six tests had been made under division 2 when it became necessary to stop explosion tests and prepare for tests on the ventilation of vehicular tunnels.[28] The work under division 3 had to be postponed.

ARRANGEMENT OF DUST LOADING IN TESTS

The method of distributing the dust was not the same as in tests in the standard test zone. The left entries were not lined with con-

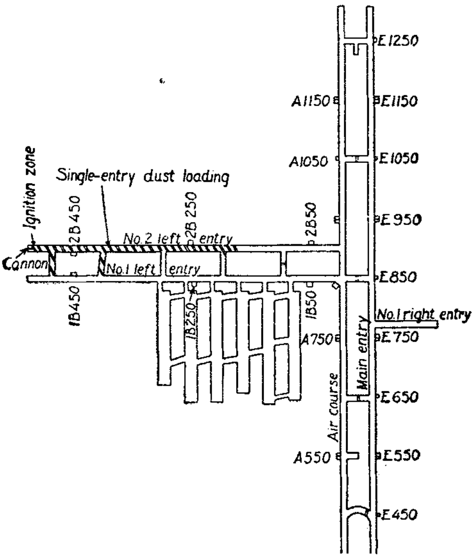

FIGURE 15.—Extent of dust loading in single-entry zone test in No. 2 left entry

crete, but had coal ribs and a dirt floor, and there were no side shelves. Because of this the entire loading was distributed on the overhead cross shelves in both left entries. The open cut-through connecting the left entries 200, 300, and 400 feet from the air course did not have cross shelves in them in the first tests (588 to 593), but cross shelves were installed before test 594 and were used in all succeeding tests. Before their installation the dust was thrown on the ribs and floor. In the tests after 594, the ignition zone (from the last

[28] This work was carried out in cooperation with the New York-New Jersey State Bridge and Tunnel Commissions, and the reports rendered to the commissions have been published in brief outline in the annual reports of the commissions and to some extent in the technical journals. See Appendix 3, Report of New York State Bridge and Tunnel Commission, 1921, pp. 91-140.

cut-through to the face of the entry in which the cannon was placed) had much the same arrangement as in standard tests; that is, the dust was on side shelves, one cross shelf, and the bench in front of the cannon, but there was no dust on the floor.

The extent of the dust loading varied in different classes of tests, but the arrangements can be divided into classes irrespective of the position of the cannon, which was at the face of No. 2 left in some tests and No. 1 left in others. The classes are as follows: (1) Tests with cannon only, (2) tests with cannon and ignition zone only, (3) tests with single-entry zone loading, (4) tests with short double-entry loading, and (5) tests with long double-entry zone loading.

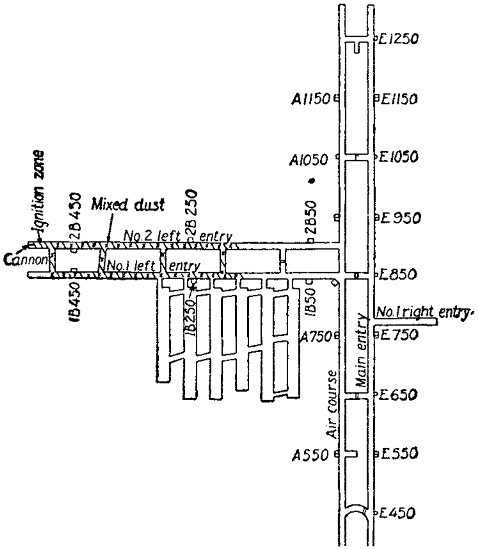

FIGURE 16.—Extent of dust loading in short double-entry zone tests in left entries

Of course there was no dust used in the arrangement for class 1, and the only dust used in the arrangement for class 2 was the 100 pounds of pulverized Pittsburgh coal dust distributed as noted in the second preceding paragraph. The arrangements of the other classes are shown best by illustrations.

Figure 15 shows the arrangements in tests 588 and 589, which were the only two tests made with a single-entry zone (class 3). The origin was at 2 B 525 in both tests; the dust outby the ignition zone extended from 2 B 475 to 2 B 175, and there was additional dust in the 475 and 400 cut-throughs.

Figure 16 shows the arrangements in the tests with a short double-entry zone (class 4). These were tests 590, 591, 592, and 594 and the origin was at 2 B 525 in all of them. The ignition zone was standard, and the mixed dust outby extended from 2 B 475 to 2 B 175, across the 475, 400, 300, and 200 cut-throughs and from 1 B 475 to 1 B 175.

Figure 17 shows the arrangements in the tests with long double-entry zones (class 5). The origin was at 2 B 525 in tests 593, 595, and 596, and at 1 B 525 in tests 597, 598, 601, 602, 606, and 607. The ignition zone was standard, but is indicated on Figure 17 only by a note. The mixed dust was distributed from the last cut-through

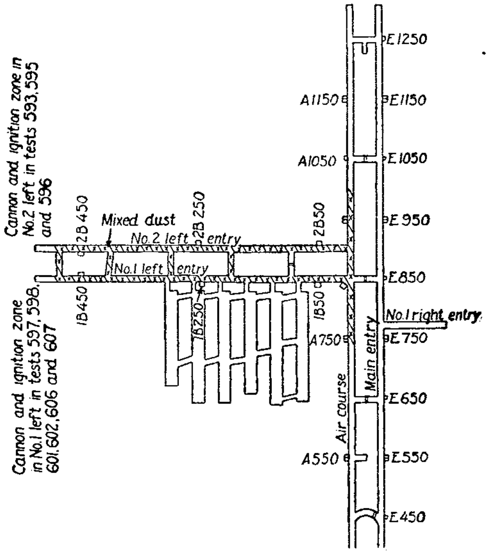

FIGURE 17.—Extent of dust loading in long double-entry zone tests in left entries

to the air course in both left entries, in all the open connecting cut-throughs, and on the air course from A 750 to A 1000.

RESULTS OF TESTS

The results of the tests with origin at the face of No. 2 left are given in Table 47, and those with origin at the face of No. 1 left in Table 48. On account of the large amount of data in them, the tables have been divided into two parts: A gives conditions and arrangements of the tests and B instrument records. The extent of the dust loading is illustrated in Figures 15, 16, and 17 for different classes of tests, and appropriate references are made to these figures in part A of the tables.

TABLE 47.—*Results of tests with origin at the face of No. 2 left entry (2 B 525). Standard ignition zone loading from 2 B 525 to 2 B 475*

PART A.—CONDITIONS AND ARRANGEMENTS OF TESTS

Test No.	Date, 1920	Mixed dust: Ratio of coal dust to shale dust in mixture	Calculated incombustible, per cent	Extent of loading	Total length of loading, feet	Rate of loading, pounds per foot	Total loading, pounds	Arrangement illustrated in—	Remarks
TESTS WITH PURE PULVERIZED PITTSBURGH COAL DUST ONLY									
588	Nov. 15	All coal.	6.2	2 B 475 to 2 B 175=300 feet; 475 and 400 cut-throughs=100 feet.	400	2.00	800	Figure 15	Compare with test 148, Bull. 167, p. 364.
600	Dec. 21	All coal.	7.7	Ignition zone only (2 B 525 to 2 B 475)	50	2.00	100		Compare with tests 376 and 599, Bull. 167, p. 170, and this bulletin, page 38.
PROPAGATION TESTS WITH 20-MESH, 10 PER CENT 200-MESH, DUST									
591	Nov. 24	70:30	35.3	2 B 475 to 2 B 175=300 feet; 1 B 475 to 1 B 175=300 feet; 425, 400, 300, and 200 cut-throughs=200 feet.	800	1.43	1,144	Figure 16	Compare with test 429, Bull. 167, p. 373.
590	Nov. 22	50:50	53.8	do	800	2.00	1,600	do	Compare with tests 372 and 427, Bull. 167, pp. 210 and 373.
PROPAGATION TESTS WITH 20-MESH, 20 PER CENT 200-MESH, DUST									
589	Nov. 18	All coal.	7.5	2 B 475 to 2 B 175=300 feet; 475 and 400 cut throughs=100 feet.	400	2.00	800	Figure 15	Compare with test 588 above.
592	Nov. 29	50:50	53.8	2 B 475 to 2 B 175=300 feet; 1 B 475 to 1 B 175=300 feet; 475, 400, 300, and 200 cut-throughs=200 feet.	800	2.00	1,600	Figure 16	To determine propagation limits in left entries with short zones and no cross shelves in cut-throughs.
594	Dec. 3	50:50	53.8	do	800	2.00	1,600	do	Conditions same as test 592, except that there were cross shelves in the cut-throughs.
593	Dec. 1	50:50	53.8	2 B 475 to 2 B 0=475 feet; 1 B 475 to 1 B 0=475 feet; 475, 400, 300, and 200 cut-throughs=200 feet; A 750 to A 1,000=250 feet.	1,400	2.00	2,800	Figure 17	To determine propagation limits in left entries with long zones and loading on air course.
596	Dec. 10	60:40	44.5	do	1,400	1.67	2,333	do	Do.
595	Dec. 5	70:30	35.3	do	1,400	1.43	2,002	do	Do.

PART B.—INSTRUMENT RECORDS

TESTS WITH PURE PULVERIZED PITTSBURGH COAL DUST ONLY

Test No.	Records obtained in No. 2 or No. 1 left entry	Maximum pressures, pounds per square inch				Time of tin-foil rupture at stations, seconds						Flame velocity between stations, feet per second				Length of flame measured from cannon, feet	Remarks
		Station 450	Station 250	Station 50	Air-course station[1]	Station 450	Station 350	Station 250	Station 150	Station 50	Air-course station[1]	Station 450 to station 350	Station 350 to station 250	Station 250 to station 150	Station 150 to station 50		
588	No. 2 left	18	36	25	9	0.228	0.407	0.447	0.639	----	----	559	2,500	521	----	(2)	
	No. 1 left	20	22	15	13	.335	.596	.637	.854	----	----	----	----	----	----	(2)	
600	No. 2 left	6	3	1	1	.253	.873	----	----	----	----	161	----	----	----	(2)	Flame 125 feet beyond end of loading in No. 2 left.
	No. 1 left	5	2	2	2	.599	----	----	----	----	----	----	----	----	----	(2)	
	PROPAGATION TESTS WITH 20-MESH, 10 PER CENT 200-MESH, DUST																
591	No. 2 left	6	2	2	1	0.300	0.820	1.192	2.059	2.750	6.072	192	269	115	145	(2)	See Figure 22 for extent of flame.
	No. 1 left	6	2	2	2	.601	1.831	2.408	----	----	----	81	173	----	----	375	
590	No. 2 left	5	2	2	1	.232	.956	7.022	----	----	----	138	16	----	----	275	Flame stopped 75 feet short of end of zone in No. 2 left and 275 short in No. 1 left; no flame in 400, 300, or 200 cut-throughs.
	No. 1 left	4	1	1	1	.982	----	----	----	----	----	----	----	----	----	125	
	PROPAGATION TESTS WITH 20-MESH, 20 PER CENT 200-MESH, DUST																
589	No. 2 left	8	6	3	3	0.224	0.583	0.784	1.170	1.758	4.033	279	498	259	170	(2)	See Figure 23 for extent of flame.
	No. 1 left	7	3	3	3	.338	----	----	----	----	----	----	----	----	----	(2)	
592	No. 2 left	6	2	2	1	.286	.830	1.462	2.784	----	----	184	158	76	----	(2)	Flame stopped 125 feet short of end of zone in No. 1 left; no flame in 300 or 200 cut-throughs.
	No. 1 left	5	2	2	2	.598	----	----	----	----	----	----	----	----	----	275	
594	No. 2 left	5	2	----	1	.299	.923	1.839	3.105	----	----	160	109	78	----	(2)	Flame stopped 100 feet short of end of zone in No. 1 left; no flame in 300 or 200 cut-throughs.
	No. 1 left	5	2	2	2	.674	----	----	----	----	----	----	----	----	----	300	
593	No. 2 left	4	2	2	1	.244	1.013	1.811	3.234	4.572	----	130	125	70	72	475	Flame stopped at 2 B 50 and 1 B 250; no flame in 200 cut-through; dust zone extended out on air course.
	No. 1 left	5	2	2	2	.616	1.906	----	----	----	----	76	----	----	----	325	
996	No. 2 left	6	2	3	1	.249	.680	1.236	2.881	2.967	3.890	232	180	----	[3] 116	(2)	See Figure 25 for extent of flame.
	No. 1 left	5	3	2	2	.517	----	2.058				----	130	----	----	450	
595	No. 2 left	6	6	6	3	.253	.540	.792	1.465	1.858	2.126	348	397	149	254	(2)	See Figure 26 for extent of flame.
	No. 1 left	7	4	5	2	.401	.710	1.401	2.158	2.219	2.753	324	145	132	1,639	(2)	

[1] For purposes of computation and plotting, station A 950 is considered a part of the No. 2 left entry branch of the explosion, whereas station A 750 is considered a part of the No. 1 left entry branch.

[2] Flame through entire dust loading.

[3] Velocity from station 2 B 250 to station 2 B 50.

TABLE 48.—*Results of propagation tests with 20-mesh, 20 per cent 200-mesh, dust with origin at the face of No. 1 left entry (1 B 525). Standard ignition zone loading from 1 B 525 to 1 B 475*

PART A.—CONDITIONS AND ARRANGEMENTS OF TESTS

Test No.	Date, 1920–21	Mixed dust							Remarks
		Ratio of coal dust to shale dust in mixture	Calculated incombustible, per cent	Extent of loading	Total length of loading, feet	Rate of loading, pounds per foot	Total loading, pounds	Arrangement illustrated in—	
599	Dec. 20	All coal.	7.6	Ignition zone only (1 B 525 to 1 B 475)	50	2.00	100		Compare with tests 376 and 600, Bull. 167, p. 170, and this bulletin, page 38.
601	Dec. 23	80:20	26.0	1 B 475 to 1 B 0=475 feet; 2 B 475 to 2 B 0=475 feet; 475, 400, 300 and 200 cut-throughs=200 feet; A 750 to A 1000=250 feet.	1,400	1.25	1,750	Figure 17	
598	Dec. 17	70:30	35.3	do	1,400	1.43	2,002	do	Compare with test 595 on page 36 and test 607, this table.
597	Dec. 15	60:40	44.5	do	1,400	1.67	2,333	do	Compare with test 596 on page 36 and test 606, this table.
602 606	Dec. 27 Jan. 5	(1) 60:40	(1) 44.5	1 B 475 to 1 B 0=475 feet; 2 B 475 to 2 B 0=475 feet; 475, 400, 300 and 200 cut-throughs=200 feet; A 750 to A 1000=250 feet.	1,400	1.67	2,333	Figure 17	To determine if stoppings in the open cut-throughs (400, 300, and 200) affected the explosion, compare with test 597.
607	Jan. 7	70:30	35.3	do	1,400	1.43	2,002	do	To determine if stoppings in the open cut-throughs (400, 300, and 200) affected the explosion, compare with test 598.

PART B.—INSTRUMENT RECORDS

Test No.	Records obtained in Nos. 1 or 2 left entry	Maximum pressure, pounds per square inch				Time of tin-foil rupture at stations, seconds						Flame velocity between stations, feet per second				Length of flame measured from cannon, feet	Remarks
		Station 450	Station 250	Station 50	Air-course station [2]	Station 450	Station 350	Station 250	Station 150	Station 50	Air-course station [2]	Station 450 to station 350	Station 350 to station 250	Station 250 to station 150	Station 150 to station 50		
599	No. 1 left	7	3	2	2	0.292	--	--	--	--	--	--	--	--	--	150	
	No. 2 left	6	3	2	1	3.787	--	--	--	--	--	--	--	--	--	100	
601	No. 1 left	14	8	10	10	.240	--	0.802	1.047	1.386	1.986	--	[3] 356	408	295	(4)	See Figure 27 for extent of flame.
	No. 2 left	12	12	14	10	.748	2.205	2.005	2.804	3.186	2.282	68	--	125	262	(4)	
598	No. 1 left	7	5	5	3	.255	.590	.854	1.180	1.446	2.300	299	379	307	373	(4)	See Figure 28 for extent of flame.
	No. 2 left	6	6	6	3	.667	1.610	1.967	4.451	6.702	2.831	106	280	40	44	(4)	
597	No. 1 left	6	2	2	2	.317	1.159	1.215	3.330	--	--	--	[3] 222	47	--	450	See Figure 29 for extent of flame.
	No. 2 left	4	2	2	2	--	--	--	--	--	--	--	--	--	--	100	
602	No. 1 left	6	1	1	1	--	--	--	--	--	--	--	--	--	--	30	
	No. 2 left	5	4	1	1	--	--	--	--	--	--	--	--	--	--	--	
606	No. 1 left	4	2	2	1	.326	.894	1.545	2.504	3.919	3.909	176	154	104	70	(4)	See Figure 30 for extent of flame.
	No. 2 left	2	3	1	--	.094	1.696	4.245	--	--	--	--	39	--	--	300	
607	No. 1 left	9	4	5	5	.216	.622	1.041	2.039	1.902	2.574	246	239	--	[5] 232	(4)	See Figure 31 for extent of flame.
	No. 2 left	5	4	7	--	.471	1.944	1.454	2.334	2.648	3.155	--	[6] 204	114	318	(4)	

1 Cannon only, no dust used.

2 For purposes of computation and plotting, station A 750 is considered a part of the No. 1 left entry branch of the explosion, whereas station A 950 is considered a part of the No. 2 left entry branch.

3 Velocity from station 1 B 450 to station 1 B 250.

4 Flame through entire dust loading.

5 Velocity from station 1 B 250 to station 1 B 50.

6 Velocity from station 2 B 450 to station 2 B 250.

In studying the instrument records, it should be remembered that the two left entries were parallel paths for the explosion, and the connecting cut throughs at 475, 400, 300, and 200 were open in all tests, except that in tests 606 and 607 the 475 cut-through alone was open. For this reason the time of tin-foil rupture at stations is given as well as the velocity between stations. It is noticeable that the explosion traveled more rapidly in the entry in which the cannon was placed. The extent of the flame has also been shown by drawings referred to in part B of the tables.

DISCUSSION OF TESTS ORIGINATING IN NO. 2 LEFT ENTRY, AND COMPARISON WITH TEST 753 IN MAIN ENTRY

Test with pulverized dust only.—The first test of the series was No. 588 and was made as a duplicate of test 148, which is described on page 367 of Bulletin 167. In test 588 pure pulverized Pittsburgh coal dust was loaded from 2 B 525 to 2 B 175, a distance of 350 feet, with additional dust in the 475 and 400 cut-throughs. The linear extent of the loading was thus the same as in test 148, but it was 175 feet farther from the air course. The barrier arrangements were not duplicated; the permanent cross shelves in No. 1 left were loaded with shale dust instead. The explosion in test 588 developed rapidly and with considerable pressure; a maximum pressure of 36 pounds per square inch was recorded 275 feet from the cannon, whereas in test 148 the maximum pressure 300 feet from the cannon had been 13 pounds per square inch.

An attempt was made to compare these results with those of the early single-zone tests in the main entry, which were reported in Bulletin 167, beginning on page 77. Any comparison had doubtful value, because the dust had been placed on cross shelves in tests 148 and 588, and the early tests in the main entry were made before cross shelves were used. In order to have a direct comparison, another test (No. 753, July 1, 1925) was made in the main entry. The loading of test 588 was exactly duplicated, except for the position of the test zone in the mine. An explosion of extreme rapidity and violence resulted. The flame velocity from E 1050 to E 950 (the last 100 feet of the zone) was 3,700 feet per second. The pressure at E 950 was such that the light spot of the Bureau of Mines manometer was deflected over the edge of the recording film and the maximum pressure was not recorded, but it exceeded 70 pounds per square inch, the capacity of the manometer. The use of the cross shelves caused a more rapid explosion development than in the early main-entry tests, but the explosion also differed materially from those made in the left entries, of which it was a duplicate.

Comparison of tests 148, 588, and 753.—The differences in explosion development are in some way connected with differences in test arrangements, which are noted in the following paragraphs.

1. On comparing tests 148 and 588, one will see that (*a*) in test 588 the point of origin was 175 feet farther from the air course than in test 148, but in both tests it faced the unbroken west wall of the air course; (*b*) the faces of the left entries were 88 feet farther in advance of the first room neck off No. 1 left in test 588; (*c*) there were six entrances into the rooms off No. 1 left in test 588, instead of four, as in test 148; (*d*) the area of the rooms off No. 1 left was more than twice as large in the later test (No. 588).

2. On comparing tests 588 and 753: (*a*) In test 753 the explosion had no obstruction facing it; (*b*) after passing the last cut-through the explosion in test 753 reached no side opening for 475 feet when No. 1 right entry was encountered (see fig. 3).

It does not follow that all of these differences were jointly responsible for the differences in explosion development. The evidence seems to indicate that relief of pressure through side openings was primarily responsible for the results obtained, and that any other effects were of a subordinate character.

Some evidence of this was given by the early single-entry tests previously mentioned, when in the absence of coal dust in the last crosscut, explosions were not obtained unless a cannon was simultaneously fired in the crosscut. This led to the use of a coal-dust loading in the crosscut and finally to the loading of the air-course zone. More direct evidence along this line was obtained in experiments by Greenwald in the steel gallery, 7½ feet in diameter, at the British experimental station at Eskmeals, England, during the summer of 1924.[29] These tests showed that when an explosion is initiated relief of pressure ahead of it would cause more rapid development, but relief of pressure behind would retard and, if the relief sufficed, prevent development of the explosion. Also, when a well-developed explosion passed an opening which afforded relief of pressure, the progress of the explosion was retarded and its velocity decreased. What the ultimate effect of such retardation would be was not determined because the size of the gallery imposed limitations. Additional evidence of the same character was obtained from the tests made near the pit mouth in the experimental mine to determine under what conditions an explosion could be initiated near the mouth of a mine. (See Bull. 167, p. 347.) The records of tests 148, 588, and 753 accord with the results of all these tests.

Flame-velocity curves.—Figure 18 shows the flame-velocity curves for the three tests, with the shock wave from the cannon, which is the first wave passing down the entry in an explosion test. In test 588 the explosion developed more rapidly at the start than did that in test 753. This may be explained by the fact that at the time of

[29] Greenwald, H. P., and Wheeler, R. V., Coal-Dust Explosions; the Effect of Release of Pressure on Their Development: Great Britain Safety in Mines Research Board Paper 14, 1925, 12 pp.

origin of the explosion there were four open cut-throughs ahead of the flame in test 588, but only one in test 753. (See fig. 14.) After the explosion in test 753 passed the last cut-through it had no further relief in the test zone, whereas in test 588 the 400, 300, and 200 cut-throughs were open. The 400 cut-through contained coal dust, but the 300 and 200 cut-throughs did not. It is probable that relief of pressure through these openings kept the flame velocity down to 2,500 feet per second in test 588, whereas it reached 3,700

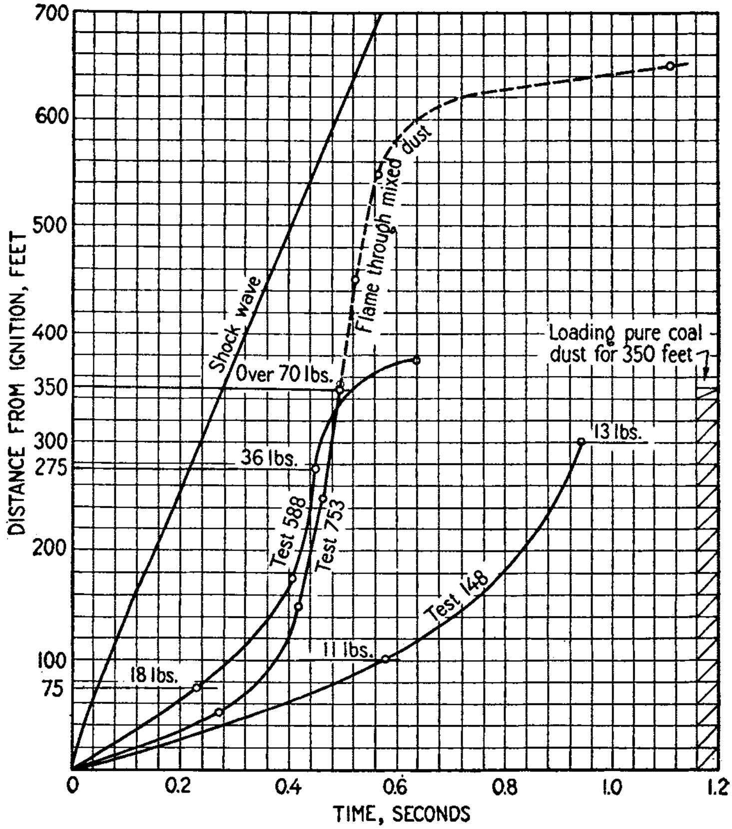

FIGURE 18.—Flame-velocity curves for tests 148 and 588 in No. 2 left entry and test 753 in main entry

feet per second in test 753. When the flame in test 588 reached the end of the zone at 2 B 175, the pressure behind it was relieved through the 200 cut-through. This relief combined with exhaustion of fuel in the main path of the explosion would cause a rapid reduction in velocity and pressure. The flame traveled outby the end of the test zone only 50 feet, a very short distance when the velocity and pressure of the explosion are considered.

In test 753 the entry immediately outby the test zone was dusty, but the dust contained 70 per cent incombustible material and was approximately 20-mesh, 20 per cent through 200-mesh, in size. Dust of this size and composition would be definitely nonexplosive as determined by the standard propagation test.[29a] The explosion wave continued through this dust with a velocity of 2,700 feet per second from E 950 to E 850, and 2,100 feet per second from E 850 to E 750. This shows that the dust present was retarding the explosion or, stated in another manner, the explosion was losing energy as it progressed. After passing E 775 the high pressure behind the explosion had opportunity for release into No. 1 right entry, and the velocity suddenly dropped to 184 feet per second from E 750 to E 650. The flame was completely extinguished before E 550 was reached. The sudden loss in velocity (or energy) would be due to the release of pressure, but the conditions made the loss evident. Had there been no relief of pressure, the explosion would have died out eventually in the dust present, and the relief merely hastened that event. The

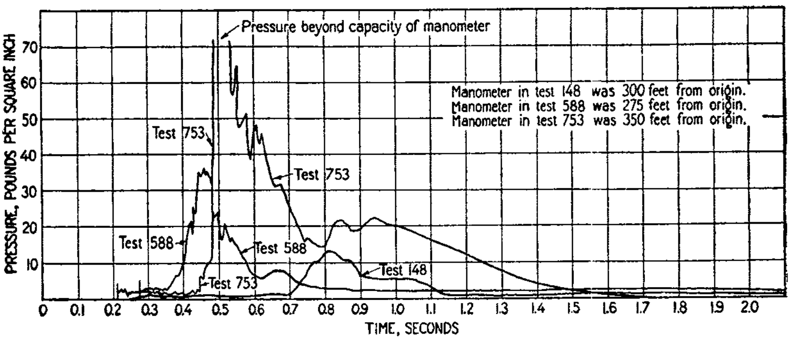

FIGURE 19.—Comparative pressures in tests, 148, 588, and 753

exact effect of the release into No. 1 right can be determined only by other similar tests in which No. 1 right is closed off with a bulkhead.

It would be desirable to make a similar comparison between tests 148 and 588, but this is rendered difficult by lack of comparable records in test 148. The pressure records offer the best basis on which a comparison of all three tests can be made.

Pressure—The development of pressure at a given distance from the origin is interesting and is illustrated in Figure 19. The stations were so arranged that manometers were not placed the same distance from the origin in all three tests, and the manometer records shown in Figure 19 are for test 148, station 2 B 50, 300 feet from origin; for test 588, station 2 B 250, 275 feet from origin; and for test 753, station E 950, 350 feet from origin.

This is close enough for a general comparison. The pressure recorded on the manometers from the shock wave was small until the

[29a] With a 50-foot ignition zone. In test 753 the equivalent of a 350-foot ignition zone of pulverized dust was used, which gave a vastly stronger initiation of the mixed dust beyond.

explosion proper arrived, when the pressure rose suddenly. A much better comparison can be made by disregarding the section of the curve before the explosion arrived and by taking the start of the sudden rise in pressure as a common time base for all three curves. This has been done in Figure 20, which shows very clearly the relative pressure development. The sharp pressure peaks of tests 148 and 588 fall very rapidly because of release of pressure into the rooms, whereas that of test 753 is sustained over a much longer period. It will be noted that the curve of test 753 drops to atmospheric pressure at about 1.7 seconds, but the drop is slower for tests 148 and 588. The reason for this is probably twofold. Cooling behind the explosion was probably more complete in test 753, because the explosion could not enter the air course after having passed the last cut-through, whereas in test 588 the flame could pass from No. 2 left through any of the open cut-throughs to No. 1 left and thus bring additional heat to the zone through which the gases must escape. Again, the release

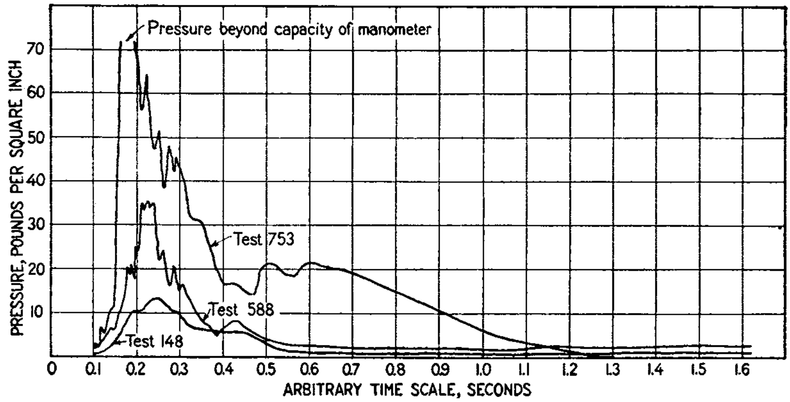

FIGURE 20.—Comparative pressures in tests 148, 588, and 753 referred to arrival of explosion as common time base

of pressure in test 753 through bodily movement of gas was out the air course directly to the atmosphere, whereas in test 588 it was into the group of rooms which had no outlet to the atmosphere, so that the pressure would rise with an inrush of gas. Complete release then would not be obtained until a later period when gas had rushed out of the left entries into the air course. This occurred at 4.5 seconds in test 588.

The explanations of the explosion phenomena put forth here are the most plausible at present available. It is expected that they will be checked as opportunity offers. Thus No. 1 right entry should be closed near the mouth and test 753 repeated, in order to determine just how much retardation was caused by release of pressure into this entry. Test 148 could also be approximately duplicated by construction of suitable bulkheads. The difficulty lies in the great expense of these tests and the fact that as theoretical work they are frequently displaced by practical problems in mine safety. As an example of expense, it may be said that test 753 cost four times as much as an ordinary standard test with mixed dust. The greater expense was due to damage caused by the explosion.

Test with ignition zone only.—In connection with the propagation tests made with the origin in No. 2 left entry, it was necessary to know the length of flame from the coal dust in the ignition zone only. This would not be the same as in the main entry, as the left entries had coal ribs and a dirt floor instead of gunite and concrete. Test 600 was made with a regular ignition zone inby the last cut-through on No. 2 left. The cannon was at the face (2 B 525). The zone outby this cut-through had been cleaned with compressed air and the ribs and roof were free of loose dry dust, but on the floor there was a quantity of dust and many coke bubbles from previous tests. The dust was sampled in two places before the test and found to contain about 49 per cent of ash plus moisture.

The flame in test 600 extended from 2 B 525 to 2 B 350 and across the 475 cut-through to 1 B 450. This is a distance of 125 feet beyond the end of the ignition zone in No. 2 left and 75 feet across the cut-through and down No. 1 left, as compared with an extension of 50 feet in tests 376 and 543 in the concreted main entry where cleaning could be thoroughly done. Evidently the dust from the dirt floor was responsible for this extra length of flame, but what effect it would have with a regular dust loading on the cross shelves can not be stated at this time.

Propagation tests with 20-mesh, 10 per cent 200-mesh, dust.—Tests 590 and 591 were made with mixtures containing this size of Pittsburgh coal dust and 50 and 30 per cent shale dust, respectively, for comparison with similar tests (427 and 429) made when the origin was at 2 B 350. Test 590 could also be compared with test 372, with origin at E 1300. The coal dust had an ash and moisture content of approximately 7 per cent and a ratio of volatile to total combustible of 40.5 per cent. The average screen analysis showed 96.4 per cent through 20-mesh, 60.2 per cent through 48-mesh, 23.7 per cent through 100-mesh, and 10 per cent through 200-mesh. Twenty-mesh shale dust was used in the mixtures.

70–30 mixture.—The 70–30 coal-shale mixture in test 591 was loaded on cross shelves from 2 B 475 to 2 B 175 and from 1 B 475 to 1 B 175, and on the ribs and floor in all the open cut-throughs. The extent of the loading is shown in Figure 16. It thus had a linear extent and arrangement similar to those of test 429, which was made when the face was at 2 B 350 (see Bull. 167, p. 373). A comparison of results follows:

Comparison of tests 591 and 429

	Test 591	Test 429
End of flame in No. 2 left	2 B 25	A 825
Length of flame in No. 2 left .... feet	500	425
End of flame in No. 1 left	1 B 200	1 B 200
Length of flame in No. 1 left .... feet	375	200

In test 591 the flame advanced in No. 2 left entry a longer distance from the face and also farther beyond the end of the test zone than in test 429. However, in both tests the flame stopped at the same point in No. 1 left. Relief of pressure into the rooms off No. 1 left was probably the main cause of the flame stopping at this point.

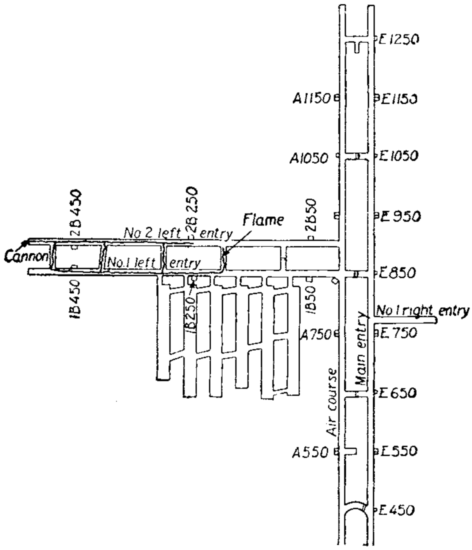

FIGURE 21.—Diagram showing extent of flame in test 591. Flame in No. 1 and No. 2 left longer than diagram indicates. See table above

Also, the instrument records show that the flame in No. 2 left traveled much faster and may have been extinguished somewhat earlier than the flame in No 1 left, and this would cause additional loss of pressure from behind the flame in No. 1 left. The extent of the flame in test 591 was longer than is shown in Figure 21.

50–50 mixture.—The 50-50 coal-shale mixture used in test 590 was loaded in the same manner as the 70–30 mixture in test 591, and the loading was similar to that of test 427, whose origin was at 2 B 350. This mixture had also been used in the standard test zone in test 372. A comparison of the results of the three tests follows:

Comparison of tests 590, 427, and 372

	Test 590	Test 427	Test 372
End of flame in No. 2 left or main entry	2 B 250	2 B 150	E 950
Length of flame in No. 2 left or main entry feet	275	200	350
End of flame in No. 1 left or air course	1 B 450	1 B 275	A 950
Length of flame in No. 1 left or air course feet	125	125	400

This mixture gave complete propagation in the standard test zone in test 372 but did not give complete propagation in either test 427 or test 590 in the left entries. The flame extended a greater distance in No. 2 left in test 590 than in test 427, a result smilar to that obtained with the 70–30 coal-shale mixture.

The instrument records of test 590 permit of some interesting deductions, and the flame and air movement records are plotted in Figure 22. The manometer pressure records have not been added, because the pressures were all low, and unless they were plotted on a large scale very little information could be obtained from them. However, the duration of the flame photograph on the manometer records is indicated. On account of the open cut-throughs the two entries may be regarded as being parallel paths, and the records for both entries have been plotted in the same direction (up) from the base line, rather than in opposite directions (up and down) from the base line, as is done with tests where there is only one open cut-through.

It will be noted that the flame reached station 2 B 350 in No. 2 left (175 feet from the origin) at about the same time that it reached station 1 B 450 in No. 1 left (125 feet from the origin). Moreover, the flame was decreasing in velocity as it traveled down No. 2 left. The flame stopped at 1 B 450, and the record shows that the tin foil ruptured about 0.1 second after the flame photograph ended on the manometer at this point. As the temperature of fusion of tin foil is much below that of visible flame this result is probably correct and indicates that the flame did not spread to the side of the entry; the foil was fused by radiant heat or else partly fused and ruptured by violence. The air-direction indicators at 2 B 250 and 1 B 250 both showed outward movement of air up to the time that the flame was extinguished in No. 1 left. At this instant they both reversed, and thereafter recorded an inward movement which was due to cooling and contraction of the gases of combustion in No. 1 left and behind the flame in No. 2 left. It is probable that the column of air and dust through which this flame was burning moved bodily inward while the flame continued to burn through it. This greatly reduced the flame velocity with reference to the walls or may even have reversed it momentarily. The inward movement of gas at 2 B 250 lasted less than 0.5 second and was followed by an outward

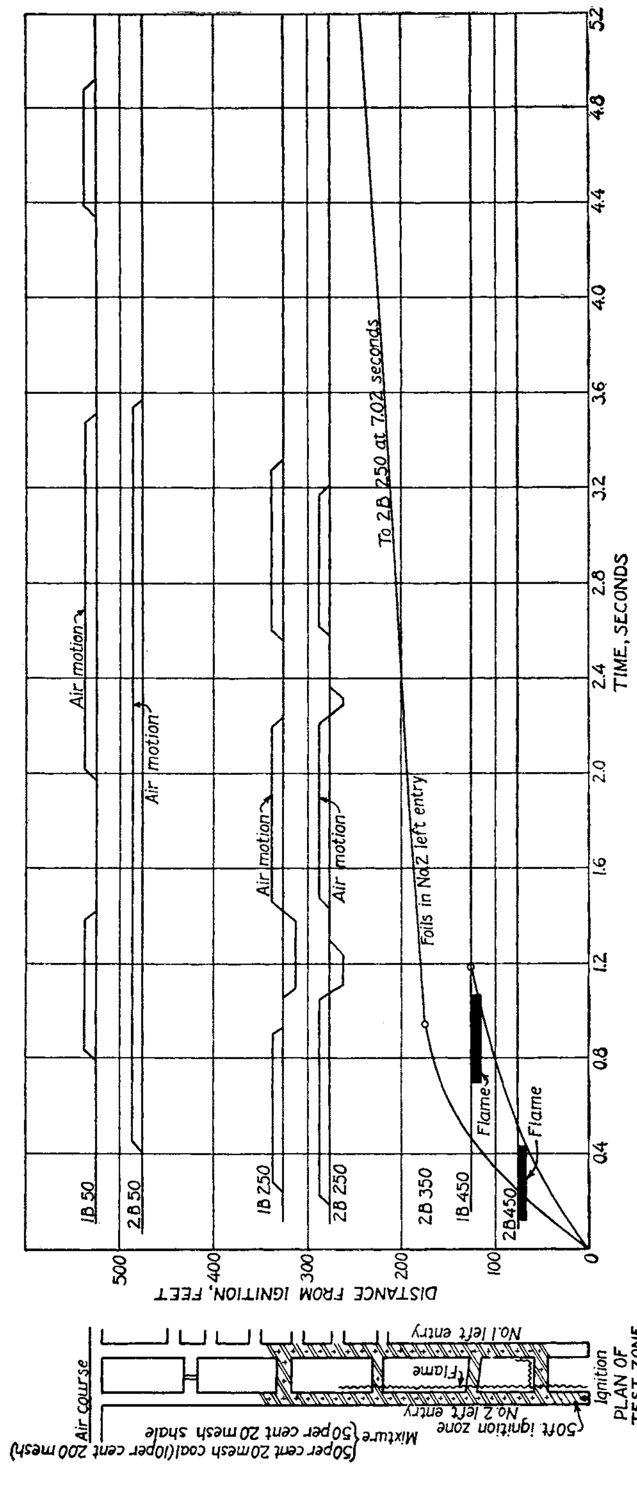

FIGURE 22.—Part of instrument records of test 590

movement in both entries of about 0.8 second duration. As there was now flame in No. 2 left entry only, some of the gas passing down No. 1 left must have come through the 300 cut-through from No. 2 left. This outward movement was followed by another inward movement of short duration, and then an outward movement, the velocity finally dropping below that necessary to actuate the instruments (about 50 feet per second). The flame continued to advance in No. 2 left during these changes, but its progress with reference to the walls of the entry was undoubtedly very irregular. After the flame passed the 300 cut-through, the pressure, owing to relief into No. 1 left and the rooms, became so reduced that the flame died out at 2 B 250.

It is noticeable that although the air-direction indicator at 2 B 250 showed three outward and two inward movements in the first 3 seconds, the indicator at 2 B 50 showed only one continued outward movement for the same period. Hence, when the inward movements past 2 B 250 occurred, the air was moving in both directions from some point of higher pressure between 2 B 250 and 2 B 50. Much the same record was obtained in No. 1 left, but during the first inward rush of air the velocity was so reduced that the instrument at 1 B 50 lost contact for 0.5 second.

Propagation tests with 20-mesh, 20 per cent 200-mesh, dust.—Six propagation tests were made with this size of Pittsburgh coal dust. The average analysis of the dust for these tests showed 7.7 per cent ash and moisture, and a ratio of volatile to total combustible of 41.1 per cent. The average of the screen tests of the dust showed 97 per cent through 20-mesh, 63.5 per cent through 48-mesh, 34.1 per cent through 100-mesh, and 20.0 per cent through 200-mesh. Twenty-mesh shale dust was used in the mixtures.

Pure coal dust was used in test 589 and mixtures containing 30 and 40 per cent shale in tests 595 and 596, respectively, while in tests 592, 593, and 594, mixtures containing 50 per cent shale were used.

Test with pure coal dust.—In test 589 the pure coal dust was distributed from 2 B 475 to 2 B 175 and in the 475 and 400 cut-throughs. The extent of the loading is shown in Figure 15. Except for the size of dust used outby the ignition zone, test 589 was identical with test 588 in which only pulverized dust had been used. The explosion of test 589 was much weaker and slower than that of test 588; the maximum pressures and velocities were about one-fifth of those obtained with the pulverized dust. The extent of the flame in test 589 is shown in Figure 23. The explosion of test 589 increased in velocity up to station 2 B 250 and then decreased steadily, giving additional evidence of the effect of relief of pressure through the 300 cut-through into the rooms. The flame-velocity curves of the two tests are compared in Figure 24. They are of the same general shape, but have different absolute values.

However, an important point is that the flame in test 589 continued 200 feet past the end of the zone in No. 2 left, reaching the air course and going 25 feet outby thereon, whereas in test 588 in the violent explosion of pulverized dust the flame had been extinguished 50 feet outby the end of the zone. This difference in behavior makes it appear probable that some other factor besides release of pressure was operating, but what this factor might be can not be determined from the limited amount of evidence at hand. Further tests are desirable.

These tests with single-entry zones were of considerable value from a theoretical point of view, but for practical conditions a double-

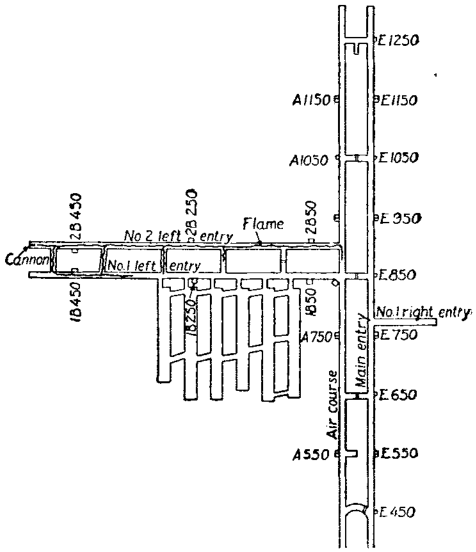

FIGURE 23.—Diagram showing extent of flame in test 589

entry loading was necessary, and it was also necessary to carry the loading into the air course a short distance in order to observe the behavior of the flame at the intersection.

Tests with mixed dusts containing 50 per cent shale.—The first three tests with double-zone loading were with mixtures containing 50 per cent shale. The short-zone loading illustrated in Figure 16 was used in test 592 and 594, and the long-zone loading illustrated in Figure 17 was used in test 593. Tests 592 and 594 were identical, except that the dust in the open cut-through was placed on cross shelves in test 594, and on the ribs and floor in test 592.

In test 592 the flame extended to 2 B 75, 100 feet beyond the end of the dust loading in No. 2 left, but stopped at 1 B 300, 125 feet short of the end of the dust zone in No. 1 left. There was no flame in either the 300 or 200 cut-throughs.

It was thought that putting the dust in the cut-throughs on cross shelves would result in a greater flame extension in No. 1 left, and the shelves were installed before test 594, which otherwise duplicated test 592. In this test the flame was 25 feet longer on No. 2 left and 25 feet shorter on No. 1 left than in test 592. There was flame in the 300 cut-through where there had been none in test 592. The use of the cross shelves in the cut-throughs evidently did not increase the length of the flame in No. 1 left. The two tests have as closely the same result as can be obtained in duplicate tests in the experimental mine.

Test 593 was made with the dust distributed throughout both left entries, and for 250 feet on the air course. The flame extended to

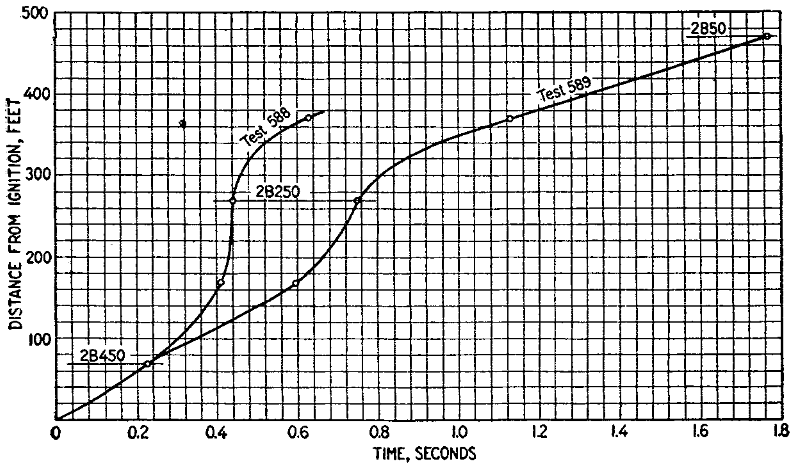

FIGURE 24.—Flame-velocity curves for tests 588 and 589

2 B 50 and 1 B 250. There was no flame in the 200 cut-through. The flame extension on No. 2 left was the same as in test 594 with the short-zone loading, but on No. 1 left it was 50 feet longer. This mixture did not give complete propagation in the left entries when dust was distributed throughout them.

A 50–50 coal-shale mixture gave complete propagation in the standard test zone in test 277. There is evidently a difference of 5 to 10 per cent combustible in the propagation limit, as determined in the main and left entries under the conditions then existing. The actual effect of a number of variables can with profit be made the subject of further investigation.

Tests with mixed dusts containing 40 and 30 per cent shale.—As mixtures containing 50 per cent shale failed to give propagation, the amount of shale was reduced to 40 per cent in test 596. The long-zone loading illustrated in Figure 17 was used. The explosion traveled out No. 2 left with decreasing velocity and extended into the air course to station A 1150, 150 feet beyond the end of the loading. On No. 1 left the flame stopped at 1 B 125. The extent of the flame in the two paths is illustrated in Figure 25. The flame in No. 1 left traveled much more slowly and probably died out there at about the time that the flame in No. 2 left reached the air course. This mixture is unsafe under the conditions of test. In the standard test zone it would give a strong explosion.

A 70–30 coal-shale mixture had been tried in test 595. The flame of this explosion extended to all parts of the dust loading, as illustrated in Figure 26. The flame traveled more slowly in No. 1 than in No. 2 left entry in this test.

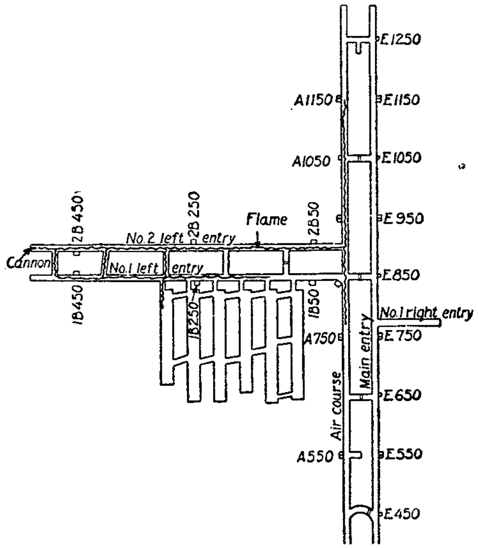

FIGURE 25.—Diagram showing extent of flame in test 596

DISCUSSION OF TESTS ORIGINATING IN NO. 1 LEFT ENTRY

Test with ignition zone only.—The fact that rooms were turned only from No. 1 left entry made desirable the moving of the point of ignition to 1 B 525 for a few comparative tests. The length of flame from the ignition zone only was determined in test 599. The flame extended to 1 B 375 and 2 B 475, distances of 100 and 50 feet, respectively, beyond the end of the ignition zone. In test 600 with origin at 2 B 525 the flame extended 25 feet farther than this in both directions. The cross-sectional area of the ignition zone and of the entry immediately outby was much larger in No. 1 left than in No. 2 left, and in addition there was the sump under the board floor in No. 1 left. Despite these hindrances the maximum flame extension was still twice that obtained in the main entries, which are concrete lined and consequently freer from dust when cleaned with compressed air.

Propagation tests with open cut-throughs.—Tests 601, 598, and 597 were propagation tests made with mixtures of 20-mesh shale dust and 20-mesh coal dust, of which 20 per cent would pass 200-mesh. The coal dust contained an average of 7.4 per cent ash and moisture. Sizing tests showed an average of 96.4 per cent material that passed through 20-mesh, 61.5 per cent through 48-mesh, 32 per cent through 100-mesh, and 20 per cent through 200-mesh. The dust in all three tests was loaded throughout both left entries and their connecting cut-throughs and from A 750 to A 1000. There was no dust

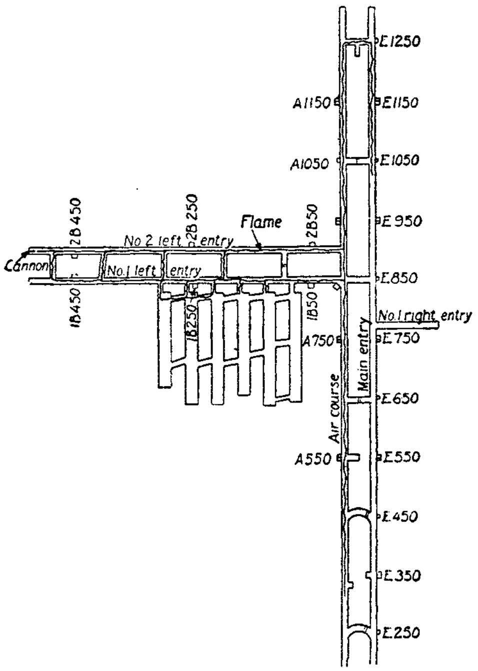

FIGURE 26.—Diagram showing extent of flame in test 595

loading in the rooms or room necks. The extent of the loading is shown in Figure 17.

80–20 mixture.—In test 601 an 80–20 coal-shale mixture was used, and an explosion of wide extent resulted. Although the maximum pressure was less than 1 atmosphere, it was fairly high when compared with other left entry tests. The flame extended to all parts of the test zone and traveled out the air course, stopping a little short of the pit mouth. It also traveled inby on the air course and out the entry to E 500, a distance of 1,000 feet beyond the end of the dust zone at A 1000. The fuel for this extension was obtained from dust that had settled out of the air current when the mine was being cleaned after previous tests. There were no barriers to limit the flame. There was also flame in all the rooms, as illustrated in Figure 27, a plan of the mine showing the extent of the flame in this test. Pressures up to 14 pounds per square inch were developed in the left entries. This test produced relatively higher pressures and flame velocities than did the single-entry loading of pure 20-mesh coal dust in No. 2 left (test 589), showing the effect of sustained pressure from a double-entry loading on the development of an explosion.

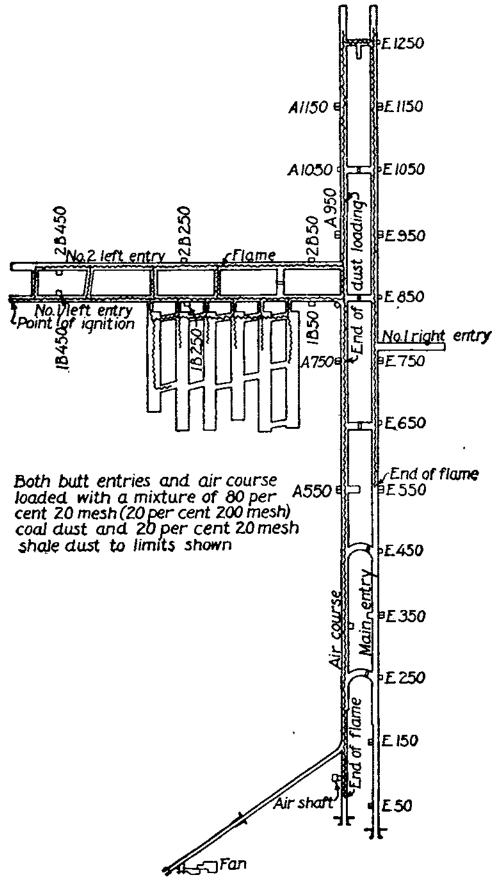

FIGURE 27.—Diagram showing extent of flame in test 601

The pressures in this explosion would be considered moderate for an explosion in the standard test zone.

70–30 mixture.—In test 598 a 70–30 coal-shale mixture was used and an explosion of medium strength developed. The flame extended entirely through the dust loading on No. 1 left and a long distance beyond the ends of the dust loading on the air course, but on No. 2 left the flame died out before reaching the air course. The last recorder on No. 2 left that gave a record was at 2 B 125, but matches in the roof and rib were burned at 2 B 100, and in the roof at 2 B 75. The tin foil at 2 B 50 was fused, although both matches at this point were unburned. Both matches were unburned at 2 B 25. The extent of the flame in this test is shown in Figure 28.

The failure of the flame to traverse the entire zone in No. 2 left seems to have been due primarily to the difference in speed of the flame in the two left entries. Reference to part B of Table 48 shows that the flame traveled much more rapidly in No. 1 than in No. 2 left. The flame in No. 1 left reached the air course at about

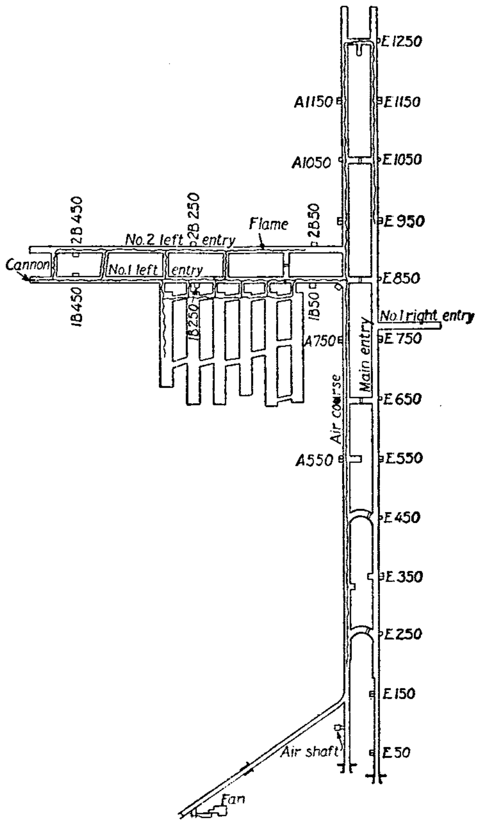

FIGURE 28.—Diagram showing extent of flame in test 598

the same time that the flame in No. 2 left arrived at 2 B 250. On reaching the air course the flame from No. 1 left branched and one part traveled inby on the air course. It passed the mouth of No. 2 left and so was directly ahead of the flame coming down No. 2 left. The pressure behind the air-course flame would tend to be relieved by movement of air into No. 2 left, which would cause retention of pressure in the outer end of No. 2 left and result in the flame therein traveling more slowly. The speed of the flame in No. 2 left decreased to 40 feet per second, a very low rate of movement for flame which continues self-supporting. The air-direction indicator at 2 B 50 showed that gas was moving out of No. 2 left during most of the time that the flame was traveling slowly out that entry. The manometers at 2 B 50 and 2 B 250 showed pressures above atmospheric, but the absolute pressure at both stations was virtually the same at all times. The pressure in No. 2 left gradually fell below atmospheric, and about 0.3 second before the 2 B 50 foil was fused the direction of gas movement reversed in No. 2 left. The flame must then have been advancing outward through a medium which was moving inward. The gas moving into No. 2 left would contain a large proportion of the burned gases from the No. 1 left branch of the explosion, and this, combined with the retrograde movement of the gas, evidently extinguished the flame.

60–40 mixture.—In test 597 a 60–40 coal-shale mixture was used. The flame extended down No. 1 left to 1 B 75 with branches to No. 2 left through the open cut-throughs. Figure 29 shows the extent of the flame in this test. Pressures and velocities were all low, and the mixture gave nonpropagation under the conditions then existing in the left entries.

COMPARISON OF TESTS ORIGINATING IN NOS. 1 AND 2 LEFT ENTRIES

The results of similar tests with origin in Nos. 1 and 2 left are compared in Table 49.

TABLE 49.—*Results of similar tests with origin in No. 1 and No. 2 left entries*

Ratio of coal to shale in mixture	Origin in No. 2 left. Flame length in—		Origin in No 1 left. Flame length in—	
	No. 2 left	No. 1 left	No. 1 left	No. 2 left
80 : 20			Through zone	Through zone.
70 : 30	Through zone	Through zone	do	450 feet.
60 : 40	do	450 feet	450 feet	100 feet.
50 : 50	475 feet	325 feet		

The results given in Table 49 show that 10 per cent more shale dust was necessary to prevent propagation when the origin was in No. 2 left. This was no doubt due to the relief of pressure into the rooms after explosions originating in No. 1 left had passed the room necks. However, it must be remembered that much of this relief was possible only because there was no combustible dust placed in the room necks to build up pressure at those points and sustain the main explosion wave in No. 1 left entry.

Table 49 also shows that when propagation was not obtained, the flame had the greater extension in the entry in which the cannon was placed. This appears to be at variance with results obtained in the standard test zone where, with the origin at E 1300, the flame extension is greater in the air course.

The explanation has been advanced that the greater extension of flame in the air course in standard tests was caused by relief of pressure ahead of the explosion into the left entries. The effect is particularly noticeable in the standard test zone, because there is no opportunity for release of pressure behind the flame until one branch of the explosion has been extinguished. When pressure can be released behind as well as ahead of the flame, conditions become more complicated. Relief of pressure ahead of the flame tends to accelerate it; relief behind the flame tends to retard it. A combined action of this sort was present in the tests in the left entries, and the result obtained must be analyzed with this in mind. It is probable that relief of pressure behind the explosion is the more important of

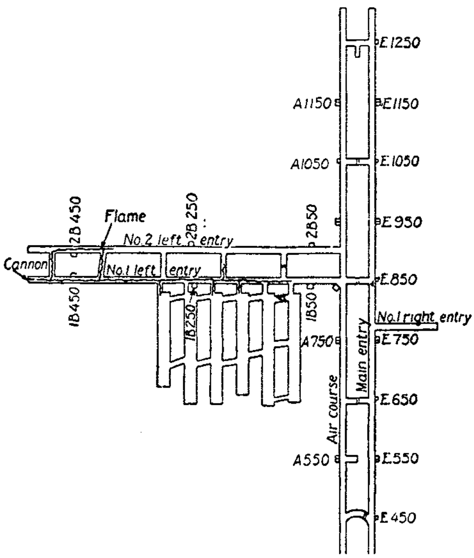

FIGURE 29.—Diagram showing extent of flame in test 597

the two, since the pressure in the burned gases behind the flame will be much higher than in the unburned gases in front of the flame.

When an explosion was originated at 2 B 525, relief ahead of it could be obtained through four open cut-throughs. When it was originated at 1 B 525, relief ahead could be obtained through these four cut-throughs and six room necks in addition. As an explosion advanced, the number of openings acting as relief ahead of the flame would decrease. These openings, after the flame had passed them, would then act to relieve the pressure behind the flame, and this relief would tend to retard it.

When the 60–40 coal-shale mixture was used with origin in No. 2 left (test 596) the flame traveled from the cannon straight out No. 2 left to the air course, but with decreasing velocity. Relief of pressure behind the flame through the four cut-throughs (this relief would have been reduced to some extent by the flame coming down No. 1 left) was not sufficient to prevent complete propagation in this entry. However, when the same mixture was used with origin at 1 B 525 (test 597) the flame traveling out No. 1 left stopped 75 feet short of the air course. In other words, the flame continued until relief of pressure through the room necks was all behind it, and then died out. Part B of Table 48 shows that in test 597, when the flame in No. 1 left passed the necks of Nos. 6 and 5 rooms, the velocity dropped suddenly from more than 200 to less than 50 feet per second.

Pressure.—In considering the flame development in the entry opposite to that in which the cannon was placed, it will be observed from Table 49 that the flame extension was greater in No. 1 left with the origin at 2 B 525 than in No. 2 left with the origin at 1 B 525. Evidently the relief ahead of the flame would be the greater in No. 1 left entry, and it was in this entry that the flame extended the greater distance. The matter is very much complicated by the difference in speed of flame in the two entries, which resulted in a given cut-through being at certain times ahead of the flame in one entry and behind the flame in the other entry. Careful study of the matter would require consideration of all the pressure, velocity, and gas-movement records obtained in each test and is much beyond the scope of the present bulletin. Work of this character is reserved for a future paper dealing with matters relating to the theory of mine explosions rather than to safety in practical mining operations. However, the surface indications are that relief of pressure ahead and behind the flame was a very important factor in the results obtained in the present series of tests.

TESTS TO DETERMINE EFFECT OF STOPPINGS IN OPEN CUT-THROUGHS

The foregoing tests were considered to have supplied much information of immediate value in connection with the lengthening of the left entries, and the problem of the effect of stoppings in the cut-throughs was then taken up. It was recognized that conditions might be different with a stopping that could be broken by the explosion than with one which could not be broken. There was no intention to test a stopping so flimsy that it would fail completely with the concussion of the cannon, which would give results little, if any, different from those obtained with no stopping at all. Such a stopping would not be practical in a mine where explosives are used in blasting coal or rock.

PRELIMINARY TESTS

The first step was to find out how strong a stopping would have to be to withstand the pressure wave from the blown-out shot. The 400 cut-through was used for these tests, as it was the second cut-through from the face and in a producing mine would have a stopping in it.

The first stopping tried (test 602) consisted of a wooden frame cemented to the rib and had 1-inch boards nailed to the frame. The boards were so fastened that they would not pull off but would have to break if the stopping failed. The clear area of this stopping inside the frame was 32.5 square feet and measured 5 feet 10 inches wide by 5 feet 6 inches high. The cannon was fired at the face of No. 1 left with no dust loading of any kind. The stopping was broken down and thrown toward No. 2 left and the boards were broken.

For test 603, 2-inch boards were substituted on the same frame and the cannon was fired again. The heavier boards were no more effective than the lighter ones and were broken in much the same manner.

For test 604, 1-inch boards were used, and a 2 by 6 inch horizontal center brace was fastened securely in place on the side of the stopping facing No. 2 left entry. The pressure waves from the cannon broke this stopping, throwing the boards toward No. 1 left and the center brace toward No. 2 left.

For test 605, a 2 by 6 inch horizontal center brace was used on both sides of the stopping with 1-inch boards as before. This stopping withstood the discharge of the cannon without damage.

TESTS WITH MIXED DUSTS

Stoppings of this character were then placed in the 200 and 300 cut-throughs, in addition to the one in the 400 cut-through. Test 606 (see Table 48) was made with a 60–40 coal-shale mixture which was loaded in both left entries and on the air course from A 750 to A 1000. This and the following test (607) were propagation tests with origin at 1 B 525. The extent of the dust loading is shown in Figure 17. The flame in test 606 extended all the way through No. 1 left and out the air course past the end of the zone at A 750. In the air course the flame stopped at A 900, 100 feet short of the end of the dust zone. The flame crossed through the 475 cut-through to No. 2 left and traveled to 2 B 275, a distance of 250 feet. The extent of the flame is shown in Figure 30. The stoppings were not affected, except that in the 400 cut-through one board was broken out below the brace, leaving a hole about 1 foot wide and 2 feet high. The conditions then were not essentially different from those that would have obtained with very strong stoppings present. Except for the presence of stoppings this test was identical with test 597, in which the flame did not extend beyond 2 B 75 and was present on No. 2 left only where it came through the open cut-throughs. Evidently the presence of the stoppings aided the propagation of the flame to some extent, probably because they caused a greater retention of pressure behind the explosion flame. They could not have been any weaker, however, or they would not withstand ordinary shot firing, as the pressures developed in the explosion were not more than 3 pounds per square inch, except at station 1 B 450 immediately outby the ignition zone.

In test 607 the broken board in the 400 stopping was replaced and a 70–30 coal-shale mixture was used. An explosion developed which was somewhat stronger than test 606. It traveled through both left entries, outby on the air course to A 150 and inby on the air course to the last cut-through (E 1250), through this cut-through and out the main entry to E 850. It broke two of the stoppings in its course. The extent of the flame is shown in Figure 31. The stopping

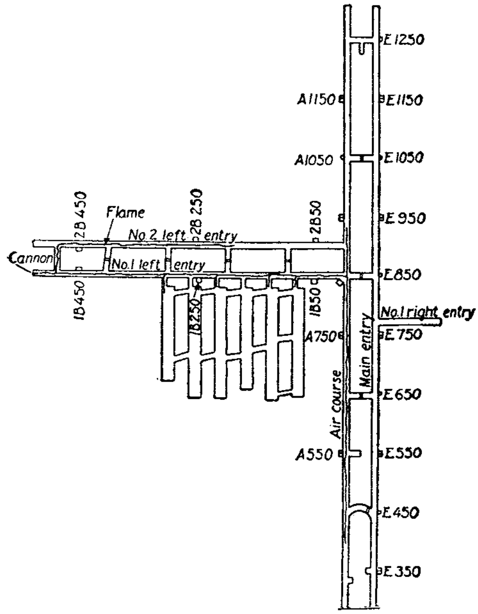

FIGURE 30.—Diagram showing extent of flame in test 606

in the 200 cut-through was not broken. That in the 300 cut-through was broken toward No. 1 left, the center brace and all but two of the boards being broken. The stopping in the 400 cut-through was also damaged but to a less extent, the center brace and several of the boards being broken. These stoppings were so arranged that the time of the first break in them was recorded on the chronograph. The 400 stopping failed before the flame arrived at 1 B 450 and the 300 stopping failed before the flame reached 1 B 350—that is, both failed ahead of the flame.

This test is comparable with test 598, in which conditions were the same except that there were no stoppings. In test 598 (see fig. 28) the flame extended throughout No. 1 left and the air course, but there was a short space on the outer end of No. 2 left in which there was no flame. Reasons for the lack of flame in this space have been stated in the discussion of test 598 on page 154. In test 607, with the stoppings present, the flame extended entirely through No. 2 left, and the failure of two of the stoppings did not prevent it. The instrument records show that the maximum pressures in the left entries were much the same in both tests, and the flame velocities were lower on No. 1 left and higher on No. 2 left in the test in which the stoppings were present. The greater development of the explosion

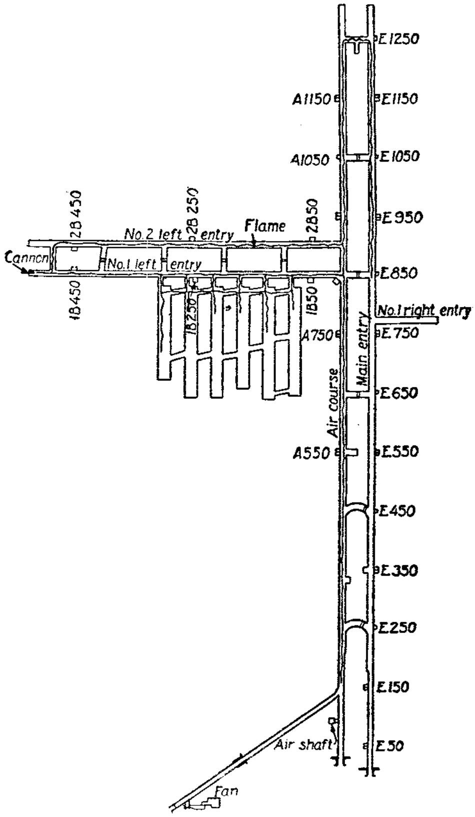

FIGURE 31.—Diagram showing extent of flame in test 607

beyond the dust zone in the air course was due to conditions in the area traversed, and is not dependent on the conditions in the left entries. The failure of the stoppings ahead of the explosion would tend to accelerate rather than retard the flame, and, as the stoppings were not completely destroyed, the openings would afford less relief to the pressure than when there was no stopping present.

Conclusions.—The only conclusion that can be drawn from this test is that the failure of the stoppings did not in any way prevent the development of the explosion. This confirms the results of tests and the conclusions reported in Bulletin 167, pages 369 to 380. In the preceding test the pressures were too weak to break the stopping, and no evidence can be drawn that favors the use of stoppings designed to break when there is an explosion. The need is for air-tight fireproof stoppings that will insure delivery of a maximum of air to the last cut-through and will not deteriorate from decay as do wood stoppings. A tight fireproof stopping must have considerable strength. If heavy shooting is done in a mine it may be necessary to use heavy brattice cloth for two crosscuts back from the face. The permanent stopping will not be affected by a weak explosion, and its failure in a strong explosion will probably not materially affect the continuation of the explosion.

SUMMARY AND APPLICATION

The results of the single-entry zone tests show that relief of pressure from behind a coal-dust explosion will greatly retard the development of the explosion. With a given loading, relief of pressure into a group of rooms with no coal dust therein resulted in explosions of lower velocities and pressures in the left entries than were obtained in the standard test zone with a similar loading. The extension of the left entries to a length of 525 feet permitted stronger explosions to develop than when they were 350 feet long, but the limits of explosibility were lower than those for similar dusts tested in the standard test zone in the main entry. None of the evidence obtained supported a suggestion made in Bulletin 167 that reflected waves from the air-course rib were responsible for any of the differences.

About 5 per cent less added incombustible dust was required to prevent propagation when the origin was at the face of No. 2 left than when in the standard test zone in the main entries. A further reduction of 10 per cent was found when the origin was moved to the face of No. 1 left. It appears that relief of pressure into the rooms was responsible for this last reduction, but there was no combustible dust in the room necks to continue the explosion there and so retain the pressure on No. 1 left. Further tests are needed to determine the effect of flame entering and continuing in the rooms.

When the origin of the explosion was at the face of No. 1 left entry, the presence in the 200, 300, and 400 cut-throughs of stoppings that did not fail caused a greater extension of flame in a given mixture than was obtained when there were no stoppings. However, it is manifestly not practicable to omit any stoppings in an operating mine. Also, an explosion will traverse the entries when pure coal dust is present, irrespective of the condition of the stoppings.

The failure of stoppings in these cut-throughs in one test did not retard the explosion, which confirms tests reported in Bulletin 167.

It appears that a properly built mine stopping would be too strong to be affected by very weak explosions, and more violent explosions continue measurably independent of its rupture.

With the advent of systematic rock dusting, the question of the effect of stoppings becomes of minor importance. The tentative specifications recommended by the Bureau of Mines were based on the results obtained in the main entries where conditions were at all times more favorable to the development of an explosion than in the left or room entries where the stopping tests were made. Explosions should be stopped at the place where they may start, ordinarily at the face, rather than after starting. After definite standards of rock dusting for roadways are adopted it becomes of primary importance to study conditions of origin and methods for preventing propagation of an explosion in the short zones between the end of the rock-dust zone and the face of the entries; that is, between the last cut-through and the face also. It is necessary to study what should be done to prevent explosions starting in rooms and in pillar workings. There is at present very little information concerning the development of explosions in rooms or other wide places.

LIMITS OF EXPLOSIBILITY OF COALS TESTED

Table 50, which follows, gives the limits of explosibility of coals tested at the experimental mine and discussed in this bulletin. Part of the data have already appeared in Tables 41 and 43, but Table 50 presents valuable computations of the percentage of incombustible required to prevent ignition of or propagation of an explosion through various mixtures of coal dust and rock dust.

TABLE 50.—*Limits of explosibility of coals tested at the experimental mine*

Index letter for—		Mining district	Coal bed	Commercial classification of coal	Ratio of volatile to total combustible $\frac{V}{V+FC}$	Percentage of incombustible required in a mixture of coal dust and rock dust to prevent—											
						Ignition of—						Propagation of an explosion through—					
						Pulverized dust when there is in the air current—			20-mesh, 20 per cent 200-mesh, dust when there is in the air current—			Pulverized dust when there is in the air current—			20-mesh, 20 per cent 200-mesh, dust when there is in the air current—		
Pulverized dust, curve of fig. 8	20-mesh, 20 per cent 200-mesh, dust, curve of fig. 10					No gas	1 per cent gas	2 per cent gas	No gas	1 per cent gas	2 per cent gas	No gas	1 per cent gas	2 per cent gas	No gas	1 per cent gas	2 per cent gas
A		Wyoming Valley, Pa.		Anthracite	0.060			(1)				(2)		(3)			
B		do		do	.066			(1)				(2)					
C		Lykens Valley, Pa.		Semianthracite	.099	(2)		25				20	36	52			
D		Bernice, Pa.		do	.102			(1)				(2)	(4)	25			
E		Cambria County, Pa.	Lower Kittanning	Semibituminous	.175	35	48	61				55	64	73			
Y	S	McDowell County, W. Va.	Beckley	do	.198	43	54	66	(5)	20	40	60	68	76	43	54	66
F		Raleigh County, W. Va.	do	do	.200	43	54	66				61	69	77			
G		Cambria County, Pa.	Upper Freeport	do	.208	46	57	68				63	70	78			
H		Fayette County, W. Va.	Fire Creek	do	.221	48	58	69				65	72	79			
I	A	Clearfield County, Pa.	Lower Kittanning	do	.254	53	62	72				68	74	80	61	69	77
J		Crowsnest Pass, British Columbia.	No. 1 (Coal Creek)	do	.270	54	63	72				70	76	82			
K		Fayette County, W. Va.	Sewell	do	.271	55	64	73				71	77	83			
W	B	Jefferson County, Ala.	Nickel Plate	do	.272	55	64	73	31	45	59	71	77	83	60	68	76
	C	Fayette County, W. Va.	Sewell	Semibituminous	.273	55	64	73				71	77	83	62	70	77
L		Indiana County, Pa.	Upper Freeport	Bituminous	.325	58	66	75				74	79	84			
X		Yorkshire, England	Silkstone	do	.374	61	69	77				77	82	86			
	D	Walker County, Ala.	Jagger	do	.375	61	69	77	30	44	58	77	82	86	54	63	72
V		Saline County, Ill.	No. 5	do	.378	61	69	77				77	82	86			
	E	do	do	do	.390	62	69	77	37	49	62	78	82	87	63	70	78
M		Harlan County, Ky.	Keokee	do	.396	62	69	77				78	82	87			
N	F	Experimental mine	Pittsburgh	do	.400	62	69	77	50	60	70	78	82	87	60	68	76
	G	Saline County, Ill.	No. 5	do	.407	62	69	77	36	48	61	78	82	87	63	70	78
U		do	do	do	.411	62	69	77				78	82	87			
O	H	Hot Springs County, Wyo.	Owl Creek	Subbituminous	.417	62	69	77	35	48	61	78	82	87	63	70	78

P	I	Las Animas County, Colo.	Trinidad coking	Bituminous	.418	62	69	77	44	55	66	78	82	87	63	70	78
Q	J	Franklin County, Ill	No. 6	do	.420	62	69	77	30	44	58	78	82	87	60	68	76
	K	Union County, Ky	No. 9	do	.428	62	69	77	37	49	62	78	82	87	60	68	76
	L	Saline County, Ill	No. 5	do	.437	62	69	77	37	49	62	78	82	87	63	70	78
	M	Sweetwater County, Wyo.	No. 1	do	.438	62	69	77	30	44	58	78	82	87	60	68	76
	N	Colfax County, N. Mex.	Raton	do [6]	.446	62	69	77				79	83	87	68	74	81
	O	Routt County, Colo.	Pinnacle	do	.446	62	69	77	30	44	58	79	83	87	60	68	76
R	P	Carbon County, Mont.	No. 4	Subbituminous	.449	63	70	78	30	44	58	79	83	87	65	72	79
	Q	Routt County, Colo.	Wadge	Bituminous	.450	63	70	78	30	44	58	79	83	87	55	64	73
S	R	Vancouver Island, British Columbia.		do	.468	63	70	78				79	83	87	63	70	78
T		Knox County, Ind	No. 5	do	.497	63	70	78				79	83	87			

[1] Ignition not obtained with pure dust and 2 per cent gas present.
[2] Propagation not obtained with pure dust.
[3] Propagation not obtained with pure dust and 2 per cent gas present.
[4] Propagation not obtained with pure dust and 1 per cent gas present.
[5] Ignition not obtained with pure dust.
[6] Coking coal.

APPENDIX.—RECOMMENDED AMERICAN PRACTICE FOR ROCK-DUSTING COAL MINES TO PREVENT COAL-DUST EXPLOSIONS [1]

1. Definitions of terms used.—The term "mine" shall include all underground excavations from which coal is hoisted or transported to the surface, through one or more openings.

The term "main haulage" shall include all underground slopes and planes, all rock tunnels, and all entries excepting those from which rooms or chambers are turned.

The term "entry" shall include all underground haulageways, travelingways, and airways, excepting working places as defined below:

The term "working places" shall include:

(*a*) Rooms or chambers; from the entry or gangway rib to the face of the room.

(*b*) Entries; from the outside of the last crosscut turned to the face of entry.

(*c*) Crosscuts or break-throughs, which are being driven between entries or rooms.

(*d*) All pillar work.

The "return air" is the ventilating current, or split of same, from the point of passing the last regular working place in the section of the mine which it has been ventilating since leaving the intake to the point of union with the main return.

"Exposed electric circuits" means any conductor or conductors of the electric circuit in the mine, other than trailing cables of permissible machines, which by virtue of their location are liable to be damaged by falls of roof, wrecks, etc., which may cause sparks or arcs in the mine atmosphere.

An "isolated panel" is a separate portion of a mine, consisting of one or more room headings, surrounded by a continuous pillar except where connected with the rest of the mine by not more than two sets of haulage and airway entries.

2. Mines to be rock-dusted.—All mines producing bituminous coal, or lignite, of any grade, and which are subject to the inspection of any State inspection service, shall be rock-dusted, unless all fine coal particles on the floor, ribs, and roof or timbers are in a muddy condition.

NOTE.—All mines producing coal other than anthracite, whether gaseous or not, are liable to dust explosions. The rock dusting of each mine is a separate problem, and must be carefully studied. Rock dusting will be most efficient in mines using either the isolated panel or longwall systems.

---

[1] Approved Dec. 30, 1925, by the American Engineering Standards Committee, 29 West Thirty-ninth Street, New York City.

This recommended practice should be used in conjunction with the detailed specifications of the Bureau of Mines (as given in Reports of Investigations, Serial 2606, May, 1924) with which it is in harmony.

3. Kind of dust to be used.—The kind of dust to be used shall be as specified by United States Bureau of Mines and subject to the approval of the State mine inspection service. It shall not contain more than 5 per cent of combustible matter, nor more than 25 per cent of quartz or free silica particles, nor absorb moisture from the air to such an extent as to cake and destroy its effectiveness as a dry dust. It may be made from limestone, dolomite, gypsum, anhydrite, shale, talc, adobe, or other inert material which meets the foregoing specifications. The lighter colored dusts are to be preferred.

4. Size of dust to be used.—The dust to be used shall be pulverized so that 100 per cent will pass through a sieve having 20 meshes per linear inch, and 50 per cent or more will pass through a sieve having 200 meshes per linear inch (40,000 perforations per square inch).

5. Parts of mine to be used.—Rock dust shall be distributed on all main haulages, all entries to the last break-through, in all rooms and pillar workings, to within 40 feet of the face, or to the last break-through, and in all return airways where hauling or traveling is done. Dust must be distributed upon top, bottom, and sides of places.

In isolated panels in which no exposed electric circuits or nonpermissible motors are used, and in which only permissible safety lamps and permissible explosives are used, protection may be given by rock-dusting the entries and by rock-dust barriers at each entrance and exit.

In other places in which no traveling or hauling is done the rock dust may be distributed by the air current into which it is blown, provided that the amount specified in article 6 is deposited, or they may be protected by rock-dust barriers, which shall be of types as specified by United States Bureau of Mines and subject to the approval of the State mine inspector service. These barriers are to be erected where they will stop an explosion either before leaving or entering each panel or section of a mine. The locations of the rock-dust barriers should be shown on the working mine maps.

NOTE.—Under this requirement all parts of the mine in which open lights, exposed electric circuits, or nonpermissible explosives are used must be dusted.

6. Amount of dust to be used.—In all places where rock dust is distributed enough shall be used so that the percentage of incombustible material in the samples of dust collected in the places shall be maintained at least 55 per cent. Along room entries or gangways where methane gas is found in the ventilating current the amount of incombustible material above specified shall be raised 10 per cent for each 1 per cent of gas. Where rock-dust barriers are installed, the amount of dust used shall be at least 100 pounds per square foot of average cross section of entry at the barrier zone.

7. **Sampling dust.**—After a mine, or any part of a mine has been rock dusted, samples of the road, rib, roof and timber dust shall be taken from time to time to determine if that part of the mine requires redusting, under the following circumstances and procedure:

(*a*) A sufficient number of samples shall be gathered in the course of a month from various parts of the mine to obtain a record of the general dust conditions, provided the points of sampling are separated not in excess of 1,000 feet measured along the entry or air course. Samples should be taken at points which appear to represent average conditions.

(*b*) Sampling shall also be done when by visual inspection the dust in a stretch or zone of entry 100 feet or more in length appears to contain coal dust in an amount that may make the incombustible content of all the dust in that zone less than 55 per cent.

(*c*) A sample shall be taken in the following manner: A groove 6 inches wide across the floor from rib to rib shall be made in the loose fine material by scoop or other means, also a 6-inch strip of dust shall be brushed from both ribs and the roof (if dust is adhering to the roof), and where the entry has timber sets, from the top of one collar, also 6 inches wide from the lagging (if any). All of the material thus gathered, and which may be conveniently gathered on a canvas or oilcloth, shall be screened through a 10-mesh screen, and that passing through this screen shall be put into a can or sack suitably labeled and be sent to the laboratory for screening through a 20-mesh screen and weighing, to determine the approximate amount of dust, per 6 inches, and for analysis or testing for incombustible content. The floor sample shall be kept separate from the rib, roof, and timber samples and separate determinations made.

(*d*) The dust in all barriers shall be inspected monthly and be kept in such condition that when the barrier comes into play the dust will fall loosely into the air.

NOTE.—The percentage of incombustible matter in the samples may be determined by the volumeter, as outlined in Bureau of Mines Technical Paper 144, or by chemical analysis, using the method recommended by the United States Bureau of Mines.

8. **Record of sampling.**—A written record shall be entered in a book kept for that purpose in the mine office, showing the location at which samples have been taken, and the results of the analyses. A map of the mine should be kept posted to show the extent of rock dusting and the location of rock-dust barriers.

NOTE.—The practice of wetting bug dust or machine dust by the use of sprays on the machine cutter bars is thoroughly recommended and should be encouraged. The practice of wetting mine cars in transit by automatic drenching sprays is recommended.

GENERAL INDEX

INDEX OF TESTS

O