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THESIS
for the Degree of
Engineer of Mines.

1910.

T 228

--- AN INVESTIGATION ---

INTO

THE CAUSES OF ACCIDENTS TO SHOT FIRERS

IN BITUMINOUS COAL MINES.

10931

By G. E. Lyman, Class of 1902.

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I N T R O D U C T I O N .

Among the many thousands of men who daily go down into the depths of the earth to dig out the wealth which Nature has hidden there, none ^{are} so surrounded at all times by as many unseen and lurking dangers as the coal miner. Subject to all the perils which confront the metal miner, he is always more or less subject to further dangers arising from the different gases given off from the coal in which he works, the nature of which he understands more or less of, depending upon his natural intelligence and desire to learn, in which latter, unfortunately, the great majority are sadly lacking. While most of them know in a general way that they are working where gases of different kinds are constantly being given off in greater or lesser amounts, and where large quantities of fine coal dust are frequently in suspension in the atmosphere of the mine, either one of which, or combinations of both, under certain circumstances, may become a source of deadly danger, comparatively few of them are capable of determining the existence of such conditions, and applying the knowledge thereof to their personal safety, as well as the safety of the men working with them in the mine.

The miner who has the ambition to educate himself sufficiently to secure from the state officials his certificate of competency as a mine examiner, or mine manager, will probably be able to test any part of the mine atmosphere and tell with reasonable certainty whether or not it is safe to work in, although he will frequently find the atmosphere apparently all right just before an

apalling disaster may occur. And he will often find an atmosphere perfectly safe for the ordinary working of the mine, as far as he is able to detect, which immediately afterward will show itself highly dangerous during the progress of the blasting. Frequently while the blasting is going on, explosions will occur which are sometimes of such violence and wide spread effect that they preclude all chance of the destruction wrought being attributable to the initial energy of the explosive used, the causes of which appear to the non-scientific investigator to be full of mystery. In some states, notably Illinois, the great number of accidents attending the shooting down of the coal have led to the enactment of what is known as the shot firing law, which requires that where more than two pounds of powder are used in a single hole, the shots shall be fired by men especially designated for the purpose after all other men are out of the ground. These shot firers are supposed to be experienced men, capable of inspecting the shots before firing and judging as to their being correctly placed and safe shots to fire, and clothed with authority to reject any shots which may appear to them to be badly placed and unsafe to fire.

This measure, while evidently a makeshift, and based on the theory that these explosions are impossible to prevent and that it is accordingly better to offer as a sacrifice the devoted shotfirers than the men who prepared the shots, and oftentimes many of their comrades, has, without any question, greatly reduced the mortality from this source, not by removing the danger from the men, but

but by taking the majority of the men from the danger. It makes no attempt to get at the bottom of the trouble and remove the causes by the employment of skilled and experienced men to perform the whole operation of preparing and firing the blasts, taking this most dangerous part of the miners' work out of the hands of ignorant and unskilled labor, where it will always be a source of danger, not only to those who are in the mine when the shots are fired, but to the property itself. This is a point which the miners' organization has always uniformly opposed, maintaining that the foreign immigrant, fresh from his native fields and vineyards, shall, upon receiving his union card, enter the mines and proceed to prepare and load his shots as though he had unlimited experience in this dangerous work behind him, resting easy in the knowledge that if anything happens through his ignorance or carelessness, the unhappy operator will be responsible and not the miner himself, should he be fortunate enough to escape with his life.

In many cases the explosions which kill so many shot firers can be directly attributed to the presence of gas, or coal dust, but often there will be explosions of terrific violence in mines which are so wet as to preclude the possibility of dust being held in suspension in the air current, and where no gas has been detected in the history of the mine. Such an instance came under the writer's observation some time ago in which his opportunities of investigation were excellent, and the results of which may perhaps throw light on other apparently mysterious explosions of similar char-

acter. It is the purpose of this paper to go over this particular incident in detail, as being the most representative case of the kind which has come within the writer's experience, and as an especially careful investigation was made in view of anticipated legal action, and the matter being further investigated by the officials of the State Mining Board of Illinois.

D E S C R I P T I O N O F M I N E .

The explosion referred to occurred in Mine No. 9 of the Madison Coal Corporation, located near Cambria, Williamson County, Illinois, on the evening of January 18, 1909, and resulted in the death of two shot firers, and considerable damage to the part of the mine in which it occurred. The mine was a comparatively new one, the shaft having been sunk only about four years, and the extremely limited area of the workings did not present any such problems of ventilation as are met with in mines having workings covering hundreds of acres. The seam of coal is of an average thickness of nine feet, of the hard, firm variety common to the Carterville field of Southern Illinois, and is known in the geological horizons of the Illinois coal measures as seam No. 7. It was worked by the room and pillar system, and no undercutting machines were in use, the coal being cut by hand picking along the pillar ribs of the entries and room necks, and shot off the solid face in the rooms, or working chambers.

The seam has on an average about 35% of volatile matter in its composition, and at some points gives off considerable methane, or marsh gas, CH_4 , although in this mine there had never been

found any trace of gas in its history, and it was considered by state and company officials alike as a strictly non-gaseous mine. Despite this total lack of gas, the mine was regularly examined for same by a certificated mine examiner, although his examinations regularly indicated the absence of any traces of it.

There was sufficient water in this part of the seam to preclude the possibility of dust being carried in suspension in the ventilating current, or of any accumulations of dry dust along the roadways and walls of the workings. As a matter of fact, the traveling ways were more often than not, muddy under foot.

The seam was only 110 feet below the surface, so that there was no great amount of roof pressure on the coal.

The map of the mine attached as Plate No. 1, shows on a scale of 100 feet per inch the extent of the workings at the time of the accident in question. (The worked out portions are colored yellow to differentiate same from the remaining pillars more clearly, and) the course of the ventilating currents throughout the mine are indicated by arrows.

V E N T I L A T I O N .

Ventilation was effected by a 22' fan, mounted a few feet back from the air shaft, and at the time of the explosion was running as an exhaust fan, thus making the air shaft the upcast and the hoisting shaft the downcast, or intake for the air. Somewhere close to 100,000 cubic feet of air per minute was passing into the mine.

which was abundantly sufficient for all purposes of ventilation, and far in excess of the amount required by law for a mine of this size and output. As a matter of fact, the mine manager had been complimented by the state inspector a few days previously on his ventilation, not only commenting on the good air at the working faces, but on the general good condition of the workings.

Recourse Recourse to the map will show that the main volume of air drawn down the hoisting shaft is split very close to the bottom, and part goes to the eastern workings and another portion to the west. The current with which we are concerned, and which ventilated the part of the mine affected by the explosion, travels from the main shaft directly out the Main West entry, and is shown on the map by consecutively numbered arrows, that the course may be more easily and accurately followed. When this current reaches the 4th North it is split again, and a portion with which we are not concerned enters here and returns to the upcast by another route, which may be followed out on the map, the volume so passing being controlled by a regulator, or adjustable opening, placed near the bottom of the main return to the upcast. The main body of the current we are following continues out the Main West entry until the 5th North is reached, which it enters and travels North along until it crosses over to the 6th entry through the two cross cuts as shown; from here it travels south to the Main West entry, reaching which it continues west to the last cross cut and passes through same to the parallel air course of the Main West entry. Turning east here, it travels in this direction until it reaches the

6th south entry, which it enters and follows to the face, passing through the last cross cut into the 5th entry and back to the main air course again; here it turns east and upon reaching the 4th south entry passes into it and traverses this and the 3rd entry as shown by plat, reaches the main air course again and continues east until it reaches the first entry south. Here it crosses itself by means of an overcast and goes direct to the upcast shaft and through the fan and is discharged into the outside atmosphere. The numbered arrows will enable this whole course to be followed out on the plat without chance of confusion.

The doors used to control the ventilation were heavy wooden ones, set in heavy timber frames, and made as nearly airtight as possible, and were so hung as to be automatically closed by the air current, if accidentally left open through any neglect of the men.

The stoppings used to close the cross cuts as the one in advance was opened up were built temporarily of wood, and quickly followed up by a wall of slate next the wood, and another wall of slate six or eight feet back of this, the interior space being filled with fine fire clay and dirt, making a very compact stopping, which after a little settling and subsequent filling up and tamping, became practically airtight. In course of time, under the pressure they were subjected to, these stoppings became so solid that quite often the removal of one of them for any reason could only be accomplished, with the greatest difficulty.

The overcasts in use were as a rule built of timber,

with ample opening to carry the required volume over the entry, and with timber side walls, which, while of ample strength to resist the pressure of the ventilating current, could offer no resistance to the force of an explosion.

It being required by law that the stable have its own separate current of air, independent of the current passing out into the workings, it was located a little to the south of the hoisting shaft as shown on the mine map, and the air passing into same was conducted as shown to the upcast without getting into the current passing out to the men at the face. About thirty mules were stabled in this place, with all the conveniences for care and comfort which are found in the very best stables on the surface.

METHOD OF SHOT-FIRING.

At this time no machines were in use in the mine, the coal being cut, or sheared by hand picking, along the pillar ribs of the entries and room necks, and shot off the face in the rooms without any mining of the coal being done at all. Ordinary black blasting powder was used for the purpose, the FF size of grain being used. According to the state mining law, in a seam of this thickness there would be allowed a maximum charge of powder equal to the contents of a cylinder 1-1/2" diameter, and 60" long, or very close to 3-3/4 pounds of this particular powder, and experience has demonstrated that in competent hands this amount is amply sufficient for doing the work required.

The shooting was done entirely by shot firers employed for the purpose, and there were four of these men regularly used in the work. They were required to make the round of the mine before the men left their working places, and inspect the preparation of the shots, and if any in their judgement were unsafe to fire, they were to condemn same and make note of the fact in a book kept for that purpose, and under no circumstances were they to fire such holes. The work was divided between the men, so that two had each side of the mine, which they were supposed to cover in company, firing their shots together, and in no case were they to separate and shoot separately of each other in order to expedite the work.

The shots were ignited by means of squibs altogether, which, if handled properly, give the men a couple of minutes to get to safety. In using squibs, the manner of preparing the shot is to wrap the powder charge in a paper cartridge, allowing the end of the blasting barrel to protrude into the powder an inch or so, tying the ends of the paper securely around the barrel, insert in the hole, and tamp securely around the barrel. This method leaves a short length of the barrel sticking out from the face, affording an unfailing means of seeing the direction at which the shot is placed. When the squib is lighted and placed in the end of the barrel, it gets down to the powder by an action a good deal similar to the familiar "nigger chaser", with which the small boy is wont to celebrate on Independence day, in this case being compelled to follow the narrow tube of the

blasting barrel direct into the powder.

It will be apparent that the leaving of the blasting barrel sticking out of the hole in the manner just described gives the shot firer a final chance to judge the nature of the hole he is about to fire, in so far as the direction is concerned, and this point alone will more often than not determine the margin between a safe and practicable shot, and the one so placed that it has no possible chance of doing the work expected of it. It might also be mentioned here that the state mining law requires the shots to be tamped with clay, or other incombustible material, and expressly prohibits the employment of fine coal for such purpose, and the shot firers were instructed not to fire any shot known to them to be so tamped.

THE EXPLOSION.

The foregoing explanations will perhaps make easier a ready comprehension of the events which transpired the evening of the explosion in question, and which cost the lives of two of the shot firers at this mine.

The four men had gone the rounds as usual, examined the shots, made report on same, and as soon as the miners were out of the ground had started on their regular round of firing, two going on the east side, and the other two taking the west half of the mine, as was customary. It is only good common sense to start firing on the return end of the air current, allowing it to carry out at once the smoke and gases generated by the successive shots, leaving a pure

atmosphere for the men to perform their work in, and in which to set off each succeeding shot, the progress of their work leading them constantly against the current of fresh air, and away from the smoke and fumes.

The men went the rounds as usual, apparently, the shallowness of the overlying strata allowing the parties on the surface to distinctly follow the progress of the work. The two men on the east side finished a few minutes before eight o'clock and coming to the bottom rang for a cage and left the mine. At about the same time the people living over the west side noticed an unusual succession of heavy shots, following each other so rapidly that the only explanation could be that the men were firing independently of each other. An unusually heavy detonation then occurred, which one resident afterward testified had shaken the bed on which he was lying. This explosion produced a very noticeable blast of air out of the hoisting shaft, being plainly apparent to the men around the tippie, and from then on no further shots were heard, nor did the shot firers come to the bottom and ring for a cage. Alarmed by the heavy shooting and its sudden cessation, as well as the blast of air from the hoisting shaft, against the normal direction of the current, the night men on top notified the superintendent and mine manager, and they arrived at the shaft very shortly afterward.

A hasty examination showed that the ventilating apparatus was uninjured, and the fan was running smoothly, although

the running of the engine indicated that it was not doing its normal amount of work, and the water gage showed a reduction of the resistance of the air courses of nearly one half, indicating that the ventilation below was seriously deranged.

A party was hastily made up, and went down the shaft. The air was good at the bottom, and there was an unusually strong current moving, which was followed west as far as the overcast. Here it was seen that the timber walls of this overcast were blown out and torn to fragments, short circuiting the air from the western workings altogether, and from the entry beyond this point there was flowing a steady current of black damp, the term given by the miners to the gaseous products of a combustion of almost any character, or to an atmosphere which will not support life, or further combustion. This put a stop to the search, as no man could penetrate such an atmosphere, and the persistence with which the body of blackdamp held its own was evidence that a serious explosion had taken place out in the western workings, making the fate of the two shot firers in that territory a mere matter of conjecture.

It was apparent that the devices by which the ventilation are controlled, viz., the doors, stoppings, and overcasts, in that section of the mine, were out of commission altogether, and that the first step would be to restore the air in the quickest manner possible. A quantity of brattice cloth was accordingly secured, and the work started. Stretching cloth over the blownout walls of the

overcast, the air was forced past this point and up to the next cross-cut, where it was found that the top of the stone and dirt stopping here was blown off bodily. Working in the foul air, this was patched up, and the fresh air finally brought up to the next cross cut, where the stopping was also found to be blown out. Patching this up, and working along in this manner from cross cut to cross cut, the way was slowly forced along the entry, every foot of progress bringing to view new evidences of the force which had been turned loose in the workings, and all hope of finding the unfortunate shot firers alive was abandoned. The tops of stoppings were blown off, timbers were broken and scattered, loaded pit cars, weighing over four tons, had been blown quite a distance up a four percent grade, other cars were torn to pieces, doors were demolished, parts of the roof torn out and badly fallen, and the entry had evidently been full of flying dirt and timbers. The track at places was torn to pieces, although laid with forty pound rails, and with ties as heavy as used in standard railroad work. Finally the 5th and 6th north entries were reached, and here in the 5th, in front of room 2, at the point indicated on the plat shown in Plate 2, were found the bodies of the two shot firers, face down, side by side, shoulders touching, where they had evidently made a last effort to keep out the fumes of the deadly afterdamp of the explosion. Although severely scorched by the flames of the burning gases, they had undoubtedly met death by asphyxiation and no marks of violence were found on their bodies.

No attempt was made to penetrate further that night, the bodies being removed and all men leaving the mine to give the fan a chance to draw out the lingering fumes of the explosion, and make possible the matter of a more thorough examination and repair of the ventilation.

Such is the chronicle of the events transpiring the night of the explosion, and while it is evident that the explosion was not of the violence which characterizes some of the great mining disasters of the gaseous seams of the country, yet it was of such a character that it would have caused the death of the greater portion of the men working on that side of the mine, had they all been below, and occurring as it did in a mine which was neither gaseous nor dusty, it presents a problem of the utmost importance to such fields. In view of the absence of gas and dust, the force developed, which made itself felt over a quarter of a mile of territory, would seem of a most mysterious character. No mere blast could have spread wreck and ruin over the territory covered here, and there must evidently have been conditions brought about in some manner which could account for the liberation of this amount of energy. To ascertain these causes and conditions was the purpose of the writer, who, in his capacity as Chief Engineer for the company, was on the scene the next morning, and was among the first to penetrate to the seat of the explosion, and who afterward accompanied other officials of the company, as well as three of the state mine inspectors, over the ground, and received the benefit of their experience in kindred matters.

I N V E S T I G A T I O N O F E X P L O S I O N .

On the map of the whole mine, Plate 1, the doors, overcasts, and stoppings blown out have been colored red, and it will be noted that the damage was confined entirely to the west side of the mine, not even disturbing the mules in the stable, who were found eating quietly, and enjoying the separate current of pure air provided for them as required by law, which had evidently not been interfered with in the least degree.

Following out the Main West entry there was no damage of any moment until the overcast at the First North West entry was reached, where as stated, the timber side walls were blown out and torn to pieces. The expanding body of heated gases had evidently travelled this far from the initial point with a constantly diminishing force, until the blowing out of the overcast walls gave it sufficient room for expansion to decrease the energy to a point where it was incapable of further damage, part of it escaping through the air shaft, and part through the hoisting shaft, causing the blast from the latter which was the first indication to those around the tibble that things had gone wrong below. From this point west, the three stoppings and the door between here and the 3rd North West entry were blown out, and here was encountered a large fall of the roof, the props being blown out and broken. About 50 feet further was found an empty pit-car, badly battered and broken up, and a few feet further two loaded pit cars were found, one turned completely over and the other still upright, but turned squarely across the track. These three pit cars

had been left at the west parting the night before, and had been blown the distance shown up a four per cent grade. The loaded cars weigh about four tons each.

All the stoppings west of here along the main west were blown out, as shown on the plat of the mine workings, and at the 5th north and south entries all the doors were blown away. In the south entries there was no damage done beyond the door, but in the north entry the damage shown was of a more violent character the further the entry was penetrated. The stoppings on the Main West from here to the face were temporary ones of wood, and were all blown out. The switchstands at the parting were torn loose and blown away, and the wreckage from the doors and stoppings was scattered around in all directions.

It will not be necessary to give any further attention to any other portion of the mine outside of the 5th and 6th north entries, as the explosion originated in these without any question, and the damage noticed elsewhere was but the results of the efforts of the energy set loose to find an outlet from the workings. Examination disclosed the fact that the shot firers had up to this point fired all the shots on their side of the mine in the proper order with respect to the air current, and that the shots in the rooms off the 6th north entry had also been fired. The trouble evidently occurred while firing the shots in the 5th entry, and in Plate 2 is shown a large scale plat of this entry and the rooms off same, showing the

results of a careful examination of this territory made by the writer in company with three of the state inspectors, as well as other officials of the coal company.

At the switch in front of room 2 is shown the point where the two bodies were found, and as previously stated, they were badly scorched, but not enough to have caused death, every indication being that they had died of asphyxiation. Just inside the room as shown was found the cap and lamp of one of the men, and a little further in was the shirt of the other, badly burnt and torn, showing conclusively that it had been on fire and hastily stripped off as the quickest way of getting free from its flames. There were three shots at the face of room 2 which had not been fired, as well as a tool box and powder can which had not been disturbed in any manner. In room 3 two shots had been fired, and there were no evidences of any disturbance in this place, thirteen empty powder kegs standing undisturbed just inside the room neck, while the entry outside was strewn with broken timbers and battered powder cans. One of the strangest features of the whole investigation was the manner in which violent destruction had been wrought at one point, and a few feet away the lightest and most easily moved articles were totally undisturbed and unharmed. The numerous powder cans shown strewn around were all empty cans, the full ones being kept locked up in the wooden boxes provided by the miners for that purpose, as required by law, and as far as could be ascertained, not a single can of powder exploded, despite

the fact that the greater portion of the entry was swept by flame throughout, evidence of this being plainly seen along the roof of the entry and in the rooms by the scorching of some of the timbers.

In room 4 two shots had been fired. The rail of the track entering this room had been bent as shown by a tie flying through the air, and just inside the room neck was tool box containing one full can of powder, unexploded. Room 5 was not working at this time, although there were two tool boxes kept there, each holding a can of unexploded powder. Room 6 also was not working, but room 7 contained three shots at the face which had not been fired. Investigation showed these three holes to have been tamped with fine coal, and it is just possible, though highly improbable, that the shot firers had condemned the holes on that account. Room 8 had one shot which had been fired.

The stoppings up to and including the third, were of stone and dirt, and were all blown out toward the 5th entry, the tops suffering most in each case. The 4th cross cut had a board stopping and it was nearly all blown out into the 5th entry, showing the force to have come from the 6th over to the 5th, in this place at least. The 5th cross cut had a pile of timber in place ready to build the stopping as soon as the 6th cross cut should be opened up to full size, this cross cut having been cut through, but the coal had not all been shot down yet and loaded out. The timber here, as well as a tool box, setting originally as shown in dotted lines, was blown out into

the 5th entry, and in this tool box, which was torn to pieces by the force of the explosion, there was a can of powder which was thrown about the entry, torn open, and several pounds scattered on the floor without exploding, although the charred condition of the top coal a few feet overhead indicated the passage of an intensely hot flame along the roof.

Nothing had as yet been found which would account for the general explosion, but on going to the face of the 5th entry there was found a shot which had been fired, but which had not blown its tamping out, the blasting barrel being yet in place. The tamping was dug out and the hole carefully measured as to size, depth and direction, and the large scale drawing of same in Plate 3 will show plainly the details of this shot, not only as regards depth of tamping and powder, but the means by which the gaseous products of the combustion of the powder escaped. There happened to be a natural fissure in the coal as shown, and the shot being unable to do the work expected of it, escaped through the fissure, enlarging it considerably in its passage, with the expenditure of a very small amount of energy beside what would have been required to have moved the coal. The shot was as poorly placed and badly miscalculated as one very well could be, and had it not blown out through the fissure, would have in all probability blown its tamping before moving the coal. The hole at its mouth was only 3' 8" from the rib, while at the end it was 3' from the rib, amounting to practically the same thing as if it had been bored perpendicularly into the solid face. The dotted line

shows how this hole should have been placed to do the work it was intended for.

The tamping was 3' 8" deep, of fire clay, and the balance of the 8' hole was filled with powder, making a charge of about six pounds, as calculated by the state inspectors and the representatives of the powder concern. The maximum charge allowable by law in this seam would have been 3-3/4 pounds. It will thus be seen that not only was the hole so placed that it was an impossibility for the powder to do the work expected of it, but it was also heavily overcharged, making a combination that is met with only too often in the coal mines, but which must be expected as long as the blasting of the coal is left in the hands of ignorant and unskilled miners.

While there was no doubt in the minds of anyone connected with the investigation that here was the starting point of the trouble, yet this shot, of itself, could not have done a fraction of the damage inflicted by the explosion which followed. Not only was six pounds of powder an insignificant amount in comparison with the energy required to spread wreck and destruction along a quarter of a mile of double entry, only ceasing when it reached and destroyed the overcast at the 1st north west entry and thus secured an outlet, but the entire fumes of its total combustion would not have been sufficient to so fill the west side of the mine with black damp that the shot firers would have been in danger of asphyxiation. So while this shot was unquestionably what started the trouble, the real causes will have to be sought further, and to this end a careful

study of the evidence and facts so far related will bring out some very interesting points.

A N A L Y S I S O F E V I D E N C E .

As previously stated all shots had been fired by these two men in proper order until this pair of entries was reached. By this time it was getting late, and the men, probably with the desire of finishing and getting out quickly, separated and began firing independently. The evidence of the people on the surface, alone, will establish this fact, for in no other way can the rapidity of the shots immediately preceding the final explosion be explained. The further fact that the shots on the rooms off the 6th entry had been fired, and some in the rooms off the 5th also, while others in between were unfired, is almost conclusive that one man must have gone up the 6th entry and the other one taken the 5th, probably with the intention of meeting at the face and leaving together. While this method of firing was all right for the man in the 6th entry, as he was constantly moving toward fresh air, and working in a pure atmosphere, the man in the 5th entry was filling the air with powder fumes which were being taken by the air current directly toward his partner.

Ordinary black blasting powder, of the grade used in this mining field, has been tested repeatedly, both by chemists employed for the purpose by the operators, and independently by the government of our own and foreign countries, and the experiments show

on an average that each pound of powder will yield five cubic feet of gas made up of the following constituents:

Carbon Dioxide,	49.7%
Carbon Monoxide,	10.8%
Hydrogen,	1.8%
Methane,	.6%
Nitrogen,	28.4%
Sulphuretted Hydrogen,	8.7%

	100.00

An examination of the above analysis will show that all of the gaseous products of the combustion of black blasting powder except the carbon dioxide and nitrogen are combustible, or in other words, of the gaseous products of the combustion a total of 21.9% are of themselves combustible. This is equivalent to 1.1 cubic feet of combustible gas per pound of powder, which is of course violently explosive under proper conditions of admixture with air.

A little calculation will show us that the mixture of combustible gases represented in the above mentioned 21.9% of the product of the combustion of the powder, taken by itself, is composed of four gases, each highly explosive under proper conditions, mixed in the following proportions:

Methane,	2.7%
Hydrogen,	8.2%
Carbon Monoxide,	49.4%
Sulphuretted Hydrogen,	39.7%

	100.00

These gases all have a very wide explosive range, with the exception of methane, which in this case is so small a per cent of the mixture as a whole that it may be neglected, especially as

the mine was known to be giving off none of this gas from the working faces, and had not done so during the life of the mine. Again, if some of the shots had been fired in close succession, as our evidence shows to have been the case here, and the air had already been depleted of more or less of its oxygen by the rapid firing and baffling of the air current, there would have been a tendency toward a larger production of carbon monoxide, owing to lack of oxygen for complete oxidation to carbon dioxide. At the same time, whether a mine is of the class called dusty or not, and on account of its wetness this mine certainly could not be accused of dustiness, whenever a shot is fired the breaking up of the coal produces more or less fine dust, from which a certain amount of gas is distilled by the heat of the explosion, and often a greater or lesser amount of incandescent carbon will be thrown out into the fumes of the powder, tending toward the reduction of some of the carbon dioxide to carbon monoxide, every circumstance seeming to tend toward an increase of the amount of the highly explosive carbon monoxide in the atmosphere.

The force of the explosion travelled down the 5th entry as evidenced by the position of the debris, and notably by the rail bent as shown at the mouth of room 4 by the tie which had been hurled end on against the rail from the north with great force, and also by the course of the flame which could be traced through the rooms in the same southerly direction, passing from one room to another through the cross cuts, and always going south toward the Main West. This could

be readily determined by a decided charring and blackening of the the props in the rooms on the north sides, although there was a significant absence of the particles of coked dust and coal which are among the chief characteristics of a dust explosion. In fact, the possibility of any of the damage here having been due to dust, other than indirectly through the chemical action of the fine coal dust thrown out by the shots themselves and acting as a producer of carbon monoxide, may be dismissed, as a dust explosion pure and simple gathers force as it progresses, feeding on the dust stirred up by its advancing blast, and ceasing only when the mine atmosphere becomes extinctive of flame, or in other words has not the oxygen left to support the rapid combustion, when it subsides, leaving a deposit of finely coked dust over everything. This explosion evidently weakened from the moment of its inception, losing force steadily as it progressed, owing to the expansion offered the heated gases, and the cooling effect of the walls, until, with the blowing out of the overcast walls, there was only sufficient energy remaining to produce the comparatively weak blast up the shaft.

The tops of the stoppings in the cross cuts were all blown over toward the 5th entry, and the powder box in the 5th cross cut was hurled in the same direction from its original position as shown by dotted lines in Plate 2, and the door in the first cross cut through which the haulage passed was blown in the same direction. This circumstance is at first more or less confusing, as it apparently

shows objects blown with great force into the very entry in which the explosion had its inception, while the natural expectation would be that just the opposite should occur. But this point can be met by a very plausible explanation.

The 5th cross cut was entirely open, as shown, while the 6th had just been cut through the preceding shift. This allowed the greater volume of the air current to pass through the 5th cross cut, while a comparatively small amount went up to the face and through the 6th cross cut. The shot firer who was shooting in the 6th entry was constantly moving toward the air coming through these two cross cuts, and the fumes of the shots he fired were hanging in the entry and rooms he was leaving behind him in his steady advance toward the face of the entry. At the same time his companion in the 5th was firing his shots and moving toward the face, traveling with the fumes which were momentarily drifting toward the man in the 6th entry. Meeting at the face they probably noted the dangerous way in which the fatal shot was placed, it being so apparent from the length of blasting barrel protruding that the merest novice could not have overlooked it, and whatever their comment, they must have lighted it and ran down the entry into room 2, seeking a safe refuge from what they regarded as a dangerous shot. If this conclusion seems a little far fetched, we will have to seek some other explanation of how the burnt cap and shirt were found there, both of which had evidently been torn off hastily while in flames. Experiment made by the writer

with the squibs in use at this mine showed that a man had time to run at least 500 feet while they were burning, allowing ample time for them to get to the place where the finding of the cap and shirt indicated they had sought refuge from the shot.

The situation when the shot at the face was fired could have been none other than that the fumes from the shots in the rooms off the 5th entry were pretty well up to the last two cross cuts, and those from the shots in the rooms off the 6th entry, which had all been fired, presented a much larger body of gases hanging in these rooms and in the entry, and probably separated from the fumes created by the man in the 5th entry by a certain amount of more or less clear air which had travelled ahead of the man in the 5th entry, since he was following the air current in his work. Then followed the blown out shot at the face of the 5th entry, which was of most violent character, sending out through the fissure a flame of great length and intensity, the heat of which would undoubtedly distill more gas from the fine coal ground out of the fissure and project it into the atmosphere already heavily charged with the combustible gases of the shots set off in the 5th entry rooms. These gases, which had been harmless before the small lights of the shot firers, when subjected to the intense flame of the shot, exploded with great violence, sending a sheet of flame through the workings in every direction, which not only caught and burnt the two shot firers who had taken refuge in room 2, but which passed through the two open cross cuts at the face and traversed the volume of pure air above

mentioned, and entering the large volume of gasses produced by the shots in the 6th entry workings, precipitated a second and even greater explosion here, blowing the stoppings, doors, and other articles previously mentioned over into the 5th entry. While there was undoubtedly two explosions, or at least two centers of pressure developed, it is very likely that the whole happening was almost instantaneous, appearing to the unfortunate shot firers as one gigantic sea of consuming flame, it being very unlikely that the force of the explosion reached them in their place of refuge. The two centers of pressure will explain any apparent discrepancy in the direction of the forces. That the flame which burned the men was of something vastly more powerful than of the six pounds of powder making up the charge in the fatal shot is evidenced by the great distance at which their burnt clothing was found, being nearly 400 feet from the shot. While badly scorched, the men were asphyxiated by the after damp of the explosion, probably mostly carbon dioxide, while trying to escape from the workings.

While nothing can excuse the preparation of such a shot, or the firing of it, yet the chances are that if the other shots had been fired in their proper order, so that each shot was set off in pure air, this shot would not have precipitated an explosion, but would have simply spent its energy on the air of the 5th entry.

While the loss of life and damage to property was small in this particular instance, it is the causes and conditions which make such occurrences possible that are of interest to engineers, and it is becoming more apparent every day to the men in touch with the situation that relief from such occurrences can only be obtained by the introduction of a discipline into the mines which shall be military in its strictness of enforcement, and the giving to skilled men such dangerous parts of the work as the loading and firing of the blasts. It is small wonder that in gaseous and dusty mines we have such appalling disasters from time to time, but when explosions are possible in mines where the natural conditions are all favorable for safe mining, due to the ignorance and recklessness of the men employed, it is an opportune time for the Government to take steps toward the necessary control of mining methods and discipline.

The accident we have just gone over in detail occurred in a mine that was as safe as Nature ever makes them, and we have seen what is possible under such conditions. The only thing that prevented additional fatalities was that the men were not below at the time. Had they been working when this happened, the larger part of those on the west side would have been killed by the after damp.

Involving as it does that hardest of all problems, how to protect men from themselves, it would seem to admit of no other solution than the introduction of a discipline and direct personal superintendence, the cost of which would perhaps double the present expense of mining.