Report to the secretary of state for the home department on the causes of death in colliery explosions and underground fires, with special reference to the explosions at Tylorstown, Brancepeth and Micklefield / by John Haldane.

THE CAUSES OF DEATH IN COLLIERY EXPLOSIONS.

REPORT

TO THE

SECRETARY OF STATE FOR THE HOME DEPARTMENT

ON THE

CAUSES OF DEATH IN COLLIERY EXPLOSIONS AND UNDERGROUND FIRES,

WITH SPECIAL REFERENCE TO THE

EXPLOSIONS AT TYLORSTOWN, BRANCEPETH, AND MICKLEFIELD.

BY

JOHN HALDANE, M.D.

Presented to Parliament by Command of Her Majesty.

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ADDENDUM.

Report on the Causes of Death in Colliery Explosions and Underground Fires; with special reference to the Tylorstown, Brancepeth, and Micklefield Explosions. By John Haldane, M.D., Lecturer in Physiology, University of Oxford, and Grocers' Company Research Scholar.

Physiological Laboratory, Oxford,
March 24th, 1896.

SIR,

I HAVE the honour to submit to you the following report as to the more immediate causes of the loss of life in the explosion at Tylorstown Colliery on January 27th; also in other colliery explosions and underground fires.

I went to Tylorstown Colliery on the day after the accident, and was afforded, both by the Management and by Her Majesty's Inspector and Assistant Inspectors for the South Wales District, much assistance in conducting the inquiry. I beg especially to mention the help I received from Dr. Morris, Medical Officer to the Colliery, without whose untiring co-operation it would have been quite impossible for me to make a complete inspection of the bodies.

The explosion happened about 5.30 a.m., and was evidently propagated through the three pits by coal-dust. Fortunately only 90 men were in the pits at the time. Of these 57 were killed, while 33 were brought out alive. Of the latter three were suffering from the effects of after-damp or burns. An account of the explosion appears in Mr. Robson's Official Report.

Along with Dr. Morris I examined 45 of the bodies. He had already examined the other 12, and his notes as to their appearances are incorporated with the notes which we made jointly in examining the rest (Appendix A.). I also examined the bodies of about 30 horses, most of which had died in the stables, while a few were found in the haulage roads. In the short space of time available before the funerals, it was impossible to make complete examinations of the bodies of the men, but in several cases we asked for, and were willingly afforded, permission to examine a sample of the blood. The bodies of 15 of the horses were very completely examined. The places where the bodies corresponding to each number were found will be shown in the plan contained in Mr. Robson's Official Report.

Examination of the Bodies of the Men.

The bodies may be divided into two classes: (1) Those of men who had been killed by after-damp; (2) those of men who had been killed instantaneously by violence. The former class comprised 52 cases, *i.e.*, 91 per cent. of the whole. A complete list of the bodies, with notes of the appearances and the causes of death, will be found in Appendix A.

I. *Men killed by after-damp.*—The external appearances of the men killed by after-damp varied very much. In 35 per cent. of the cases there were no marks of burning or mechanical violence. In many of the remaining cases the face, hands, and other exposed parts of the skin, were more or less covered by a thin layer of adherent coal-dust, giving in extreme cases the appearance sometimes described as that of "charring." In no case, however, was there real charring of any part of the bodies. On rubbing off the coal-dust we found that the skin was essentially intact, except for loosening of the outer layer of the epidermis, and congestion of the underlying dermis in many parts. The blackening was evidently produced by the skin being covered during or immediately after the explosion with a layer of coal-dust, which had adhered firmly. This had been partly washed or scrubbed off some of the bodies after death, when it could be seen that the marks of burning or scalding (congestion, in the midst of which was still adherent coal-dust) associated with the layer of dust were often distributed more or less in blotches, almost as if some hot liquid had been projected in drops against the skin. Often the adherent coal-dust was only present on one side of the face or body—probably the side which had been exposed to the blast of the explosion. On microscopical examination, the adherent dust taken from one of the bodies (No. 43), was found to consist of both angular and rounded (fused) particles, the former greatly predominating. In many cases the outer layer of epidermis covering the backs of the hands was completely loosened, so that it could be peeled off in the same way as when a poultice or moist dressing has been applied for some time. On removing pieces of the loosened epidermis, we noticed that as a rule the underlying skin on the back of the hands and fingers was quite white and free from congestion. It was only towards the palmar surface, where the blood supply is normally more abundant, that a red colour could be seen. The most constant sign of burning was singeing of the hair, moustache, or whiskers. In some cases most of the hair was singed off. There was no lymph beneath the loosened epidermis, showing that it had not been separated by ordinary blistering. In some cases the superficial burning or scalding seemed sufficient from its extent to have ultimately caused death apart from the effects of after-damp, but it was difficult to form any very reliable judgment on this point. Besides that associated with coal-dust there was in some cases burning which had apparently been caused by flame or heated air alone. This was indicated by singeing of the hair, congestion of the skin (and sometimes loosening of the epidermis) in parts which had in all probability been facing a blast of heated air or after-damp.

Frequently the inside surfaces of the mouth and nose were covered with coal-dust. This suggests the possibility that some of the men might have been killed by suffocation from mechanical obstruction of the air passages by dust. In no case, however, was death due to this cause. Had it been so, the blood could not have had time to become highly saturated with carbonic oxide, as was invariably the case when much dust was found in the mouth. Moreover an examination of the air passages of the dead horses showed that only a trifling amount of dust had entered the trachea and bronchial tubes, and that there was no obstruction of any kind. We noticed no definite signs of scalding inside the mouth.

A small proportion of those who died from after-damp had received mechanical injuries, such as bruises, fracture of the limbs, dislocations, fracture of the jaw, or fracture of the skull. The latter was in one or two cases evident, and in others probable from the existence of oozing of blood from the ears. The nature of these injuries is noted in Appendix A. In two cases injuries of this kind would undoubtedly have caused death even if the men had survived the after-damp.

I now come to the characteristic appearances which indicate beyond doubt the actual cause of death. In nearly every case of death from after-damp the parts of the skin or mucous membrane, through which the colour of the blood could be observed, had a red or pink colour, instead of being leaden-blue or pale, as is the case in death from any other cause. This reddening, as seen in the face, hands, &c., often gave the bodies an extraordinary appearance of life. In the congested parts the colour sometimes appeared pink, sometimes of a red resembling sealing wax, and sometimes of a more coppery red. These varieties seemed to depend on differences in the natural pigmentation of the skin, and not on differences in the colour of the blood. In some cases the face was pale, so that the red colouring was not very evident. On the lips the pink or carmine was usually well marked, though sometimes they also were pale. Often it was necessary to rub away the coal-dust from the inside of the lips in order to see the colour. On the neck, chest, and shoulders, it was often present in irregular patches, and one or two red coloured veins could also sometimes be distinguished. The nails were pink, but the characteristic colour could be distinguished best of all in the cases where the epidermis could be peeled off the hands; in such cases the deep skin of the back parts of the hands and fingers was usually pale, but on the palmar surface the bright carmine red colour of the blood was exceedingly striking. A single glance at this part was sufficient to determine the cause of death.

There seemed to be only one cause which could account for the carmine red colour of the blood, namely, the presence of carbon monoxide. To make certain, we examined the blood on the spot with the spectroscope in the first two houses which we visited together. One of the bodies from which blood was taken was singed and much blackened by dust, while the other showed no signs of burning, and had been found beside a lighted lamp. The blood was obtained by opening the external jugular vein, and was of a dark carmine-red colour. A drop was diluted with water until the two absorption bands came out sharply on examining the solution in a test tube. Ammonium sulphide solution was then added to absorb the oxygen present, and the solution slightly warmed. The bands remained almost as sharp as before, which indicated not only that carbon monoxide was present, but that the hæmoglobin was nearly saturated with it. Had the blood been normal, or had only a moderate quantity of carbon-monoxide been present the two bands would have been replaced by the single band of reduced hæmoglobin. Next morning I determined by daylight the percentage saturation of the hæmoglobin with carbon-monoxide. The method employed was the colorometric one which I recently described in the Journal of Physiology (Vol. XVIII., p. 430). The hæmoglobin in both cases was 79 per cent. saturated (*see* Appendix A.

for analytical data). This result is of special interest, as showing, I believe for the first time, the percentage saturation of the blood at the moment of death from carbon monoxide poisoning. The inferences to be drawn from the analysis will be discussed more fully below (pp. 16 and 22).

It might be suspected that in some cases the red colour of the exposed surfaces was produced after death by absorption of carbon monoxide through the skin or mucous membrane, and that death was due to other causes, such as burning or shock. The blood of the jugular vein, from which the specimens of blood were taken in the two cases just referred to could not, however, have been affected by post-mortem absorption of carbon monoxide; and the colour was just as well marked in less exposed parts, such as the inside of the lips, or beneath the thickened epidermis on the front of the hands, as in more exposed parts, such as the skin of the face. In one case a man had sustained a bruise on the face during the blast of the explosion, and there was a small swelling containing blood underneath the mucous membrane of the lip. This blood, which had evidently been effused at once, was dark blue, while the rest of the lip, through which the blood had circulated freely until death, was carmine-red. Had diffusion of carbonic oxide through the skin or mucous membrane been capable of reddening the underlying blood, this effused blood would have been red like that of the rest of the lip. Further evidence on this point was presented by the appearance of the bodies of men who had evidently been killed at once. In these cases the colour of the blood in the bodies was blue, whenever it could be distinguished (Appendix A., Nos. 2, 20, 56.) As these bodies, all of which were burnt more or less, must have lain in the very midst of the after-damp, it seems clear that there was no considerable absorption of carbonic oxide through the skin after death.

In two cases (Nos. 19 and 21) of suffocation, the appearances differed somewhat from those just described. The colour of the face and lips was reddish blue, instead of bright red or pink. The face was intensely congested. The veins on the front of the face, neck, and upper part of the chest were distended and visible, a network of blue veins being particularly prominent on the upper part of the chest. It seems probable that in these cases death was due to acute suffocation, produced either by complete or nearly complete absence of oxygen in the air, combined with the presence of carbon monoxide, or by the presence of so large a percentage of carbon monoxide that death took place before there was time for the venous blood to become more than partially saturated with carbon monoxide (*see* p. 22).

In two cases there was no marked reddening of the blood. A sample of blood taken from one of these bodies (No. 42) showed no trace of carbon monoxide bands when examined with the spectroscope, and no carbon monoxide was found on analysis. As no marks of burns or violence sufficient to cause immediate death were present, it seems probable that these men had died in fresh air some hours after the explosion (without recovering consciousness) from the after effects of poisoning by carbon monoxide, and that sufficient time had elapsed before death for the blood to free itself (wholly or partly) from carbon monoxide. The body of one of these men was found, about ten hours after the explosion, close to a man who was still alive, and who recovered under treatment by Dr. Morris. As to the time required for the blood to free itself in fresh air, after being about three-fourths saturated with carbon monoxide, I believe that about six hours would suffice. This opinion is based on the results of the experiments on myself recently described in the Journal of Physiology (Vol. XVIII., p. 447.)

In most of the bodies decomposition was already far advanced, even within 48 hours of death. The fact of the bodies having lain for about a day in the warm air of the pit seemed to have greatly hastened decomposition.

Men killed by violence.

In the five cases in which death was instantaneous the injuries inflicted gave evidence of great violence. In one case (No. 56) the head, legs, and arms were torn from the body. In another (No. 36) the mutilation was nearly as great. In No. 6 most of the skull and brain were smashed away. In No. 43 there was fracture of both arms, dislocation of one hip joint, and apparent fracture of the skull. In No. 35 there was dislocation of the spinal column and one shoulder, and fracture of the skull and one arm.

Appearances of the Bodies of the Horses.

I first examined the bodies of a number of horses which were lying in one of the stables near the No. 7 pit, and which could not be removed at once on account of very heavy falls which had blocked the road. Most of these horses were lying with the fore leg and hind leg of one side in the air, and in many cases one or more shoes had been kicked off. The coats and tails of some of those nearest the entrance had been singed more or less by the explosion, but the burning did not seem to be at all serious. At places where the skin was exposed the carmine red colour of the blood could in some cases be plainly distinguished. Decomposition was already far advanced, 53 hours having elapsed since the explosion, and the warm air of the pit being very favourable to rapid putrefaction. It was with some difficulty that I obtained specimens of blood from the veins in the neck. At first nothing but gas issued from the incisions. Samples from a mule and a horse (No. 1) were analysed. The hæmoglobin of the mule was 59 per cent. saturated with carbon monoxide. That of the horse, which was lying further in, and was not even singed, was only 20·5 per cent. saturated. With the spectroscope test, which is much less delicate than the colour test (*see* p. 20) I could not detect any trace of the carbon monoxide bands.

The horse had almost certainly died in the fresh air after its blood had been freed of most of the carbon monoxide absorbed. The mule had also, in all probability, not died until some of the carbon monoxide had been eliminated. The stable was near the down-cast shaft (No. 7), and would be reached by more or less fresh air very soon after the explosion. Horses, which afterwards died, were observed still alive in the pit by rescuers.

The next horse examined was one which had apparently been killed by the effects of after-damp, but which had lived for about 15 hours after the explosion. Its coat was singed behind. When the body was cut up, 36 hours after death, the muscles and other parts did not present a pink appearance, but had the ordinary bluish colour when first cut into. The air passages were free from coal dust, and were not congested, but the inside of the trachea was covered by a thin layer of a greenish oily looking fluid, consisting apparently of mucus stained with coal-dust or tarry material. A sample of blood from the right side of the heart had the usual dark colour, and was found on analysis to contain no trace of carbon monoxide. As the burns seemed insufficient to account for death, this horse had apparently died from the after effects of carbon monoxide poisoning. A man who escaped alive from the same stable suffered considerably from the after effects of his exposure to the poisonous air. During the 15 hours that had elapsed previous to death the blood of the horse must have completely cleared itself of carbon monoxide. This observation is important as showing that even in the case of so large an animal as a horse, with a considerably slower rate of circulation and respiratory exchange than a man, less than 15 hours may suffice for the blood to clear itself after partial poisoning by carbon monoxide.

Fourteen other horses from No. 8 Pit (both east and west sides) were also examined as they were being cut up, three days after the explosion. The coats of most of them were more or less singed. In only one case was a fracture discovered. One or more shoes had in several cases been kicked off. In every one of the bodies the colour of the muscles, skin, and subcutaneous tissue was bright carmine red, so that a single glance was sufficient to determine the cause of death. So far as I could judge, the tint of the congested parts of the muscles was about the same in all these bodies. Samples of the blood from the right and left sides of the heart were taken from two typical cases (*see* p. 37). The appearance of the stomach and intestines varied much according to the amount of congestion. In some cases the red or pink colour was very evident at parts, in others the intestines were quite pale. The peritoneal surface was, in most cases, apparently roughened, so that at first I thought there had been commencing peritonitis. There was, however, no corresponding injection of the blood vessels, and on closer examination the roughening turned out to be due to countless small bubbles of gas, which were enclosed beneath the peritorium. The same appearance was often seen on the inner surface of the trachea. The gas had, of course, been formed after death. I have noted this appearance, because it is probably not infrequent in decomposing bodies, and I have not seen any account of it before. It seems not improbable that loosening of the outer layer of the epidermis, observed in the bodies of men who have lain long in a pit, may sometimes be due to gas produced in a similar manner. The liver was not congested, and on incision had almost invariably a markedly pink tint. The kidneys when examined had a similar colour. The spleen seemed in no case unusually distended, and was sometimes red, but usually so dark in colour that I thought the contained blood must be nearly free of carbon monoxide. Two samples were therefore taken of the dark coloured bloody fluid which exuded on incision. It turned out, however, that this blood contained only a little less carbon monoxide than the blood of the heart. The dark colour seemed to be due partly to pigmentation, partly to the fact that the organ contains such a large proportion of blood. In a few cases, where there seemed to be less blood present, the pink colour was very distinct. The blood itself, when undiluted and looked at in bulk, had a dark purplish red colour, about the shade of ripe Morella cherries. On examining it microscopically two or three days later, I found that the corpuscles had dissolved, and that it was full of pink crystals of carboxyhæmoglobin.

The lungs were pink to carmine red, mottled with the black due to the constant inhalation of coal-dust in the mine. In no case was there any excessive congestion, or œdema. The bronchi were free from coal-dust or fluid, and their inner surface looked perfectly normal. The trachea sometimes contained a little coal-dust, but only a very trifling amount. As a rule the inner surface was bright pink, and seemed a little congested, owing perhaps to the inhalation of irritating vapour or gas. There was never, however, any sign of mucous discharge or swelling. The outside of the mouth was usually black with coal-dust, but in other respects looked fairly normal. The heart cavities, when examined, contained only a little partially clotted blood, and it was not possible to obtain more than about 50 to 100 cc., even from the right side, which contained most.

After I had left Tylorstown a number of other dead horses were brought up from stables and roads and examined by Mr. David Rees, veterinary surgeon, who assisted me in examining the horses already referred to. He reported that the carmine red colour of the organs was present in every case. It thus appears that all the horses examined had been killed by carbon monoxide poisoning. In no case were appearances met with (signs of blocking of the circulation) suggestive of acute suffocation by deprivation of oxygen.

Symptoms produced in Rescuers by After-damp.

After-damp was encountered by Mr. Hannah, the General Manager, who, by descending as far as possible in the cage, and then sliding down a guide rope among the débris encumbering the bottom of the shaft, entered the No. 7 pit soon after the explosion. Accompanied by a fireman, he proceeded with great daring to explore the pits in search of men still living. He told me that after getting some distance along one of the main roads, he began to feel weak, and was unable to walk steadily. He also felt drowsy, had frequently to stop and sit down, and had much difficulty in climbing over the falls. His lamp was not extinguished by the after-damp.

Still more serious symptoms were experienced by a party who endeavoured to enter from one of the Ferndale pits communicating with the Tylorstown workings. Mr. Thomas, Manager of Nos. 1 and 5 pits, who was leading this party, and a companion were rendered unconscious for a short time, and were themselves rescued with difficulty. They entered the No. 6 Tylorstown pit through the separation doors, and at the first attempt had penetrated nearly as far as the place where a number of men were afterwards found dead with their lamps burning. Feeling affected, they went back into the fresh air behind the doors, and after a short time made another attempt to penetrate along a road leading towards the shaft. After walking some distance they began to feel weak, and endeavoured to return to the doors, but, before they reached them, first one and then another of the party dropped and became unconscious. Fortunately the precaution had been taken of leaving several men behind in the fresh air, and they at once came to the rescue, and succeeded, though with great difficulty, in dragging the disabled men out.

Mr. Thomas told me that even when the air was most poisonous his lamp burned perfectly, and he himself was under the impression, just before he fell, that he was getting into fresher air. On getting into the after-damp he had felt smarting of the eyes, but the first definite symptom was loss of power over the legs. He and his companions sank helpless to the ground with very little previous warning. They were brought back to the shaft lying unconscious on trucks. On recovering consciousness those affected had severe headache, and nausea or vomiting, accompanied by shivering.

A member of the party, who was not so seriously affected, told me that when he got into the after-damp he felt smarting of the eyes and dryness of the throat, though these symptoms caused no serious inconvenience. At the same time he felt his legs becoming more and more unsteady, and he could make no extra exertion. At this time he thought his lamp was burning somewhat dimly.

The only gas which could, under the circumstances, cause such symptoms as those described, is carbonic oxide. The same symptoms are caused by great deficiency of oxygen in the air, but from the fact that the lamps still burned fairly well, there must have been at least 18 per cent. of oxygen in the air, and with that percentage there could be no symptoms due to deficiency of oxygen. The symptoms caused by excess of carbonic acid are quite different in character, as also are those caused by sulphurous acid, sulphuretted hydrogen, or any other gas which might possibly be present. The only symptom not due to carbon monoxide is the smarting of the eyes and slight irritation of the air passages. These symptoms, as shown below, were very probably due to the presence of a very small amount of sulphurous acid.

The Composition of After-damp.

The after-damp of a colliery explosion has not yet been satisfactorily analysed. I had hoped to obtain a sample at Tylorstown, but when I reached the pit I was assured that none was present in any part of the workings. In the absence of direct evidence, however, it is possible, from various data, to obtain a rough idea of its composition.

It is evident, in the first place, that the composition of undiluted after-damp,* may vary firstly, according as the explosion is one of dust, or of fire-damp alone, and secondly, as the proportion of oxygen present in the track of the explosion is sufficient or not to consume the whole of the combustible material (gas or dust) present in the air.

The simplest case is that of an explosion of fire-damp in presence of excess of pure air, and this may be considered first. The fire-damp, or explosive gas, met with under ordinary circumstances in the coal mines of this country, appears to be nearly always simply methane or marsh gas (CH_4).

When marsh gas explodes in presence of excess of air, the reaction is as follows—

$$CH_4 + 2O_2 = CO_2 + 2H_2O.$$

The nitrogen of the air takes no part in the explosion, but for every two volumes of oxygen consumed, or for every volume of carbonic acid found, nearly eight volumes of nitrogen (and argon) will be left behind. Hence a simple calculation† will show that after the aqueous vapour has condensed the undiluted after-damp will consist of—

Nitrogen	87·23	88·28
Argon	1·05	
Carbonic acid	11·72	
	100·00	

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* By undiluted after-damp is meant the residual mixture of gas after deducting the air present. The latter is estimated from the oxygen percentage.

† The calculation is as follows. Pure dry air consists of—

Oxygen	20·93	
Nitrogen	78·10	
Argon	0·94	(according to analyses recently published by Kellas.)
Carbonic acid	0·03	
	100·00	

To just consume the whole of the oxygen it would be necessary to add to every 100 volumes of air $\frac{20 \cdot 93}{2} = 10 \cdot 465$ volumes of fire-damp or methane.

This mixture would amount to 110·465 volumes, and would consist of—

Oxygen		18·95
Nitrogen	70·71	71·55
Argon	0·85	
Carbonic acid		0·03
Fire-damp (*i.e.*, Methane)		9·47
		100·00

After the explosion, the hot after-damp would consist of—

Nitrogen	70·71	71·55
Argon	0·85	
Carbonic acid		9·50
Aqueous vapour		18·95
		100·00

Neglecting the aqueous vapour, which would soon nearly all condense in a pit, the composition of the after-damp would be that stated above.

This mixture will, under the pre-supposed conditions, be diluted with more or less of air. As it requires the presence of from 5 to 6 per cent. of fire-damp to render the air inflammable, there will not be more than 10·5 of oxygen, or 50 per cent. of pure air left in the residual gas. On the other hand, if the explosive mixture contained as much as 9·47 per cent. of fire-damp, there will be no oxygen left in the track of the explosion.

The undiluted after-damp from an explosion with excess of air would have a specific gravity of 1·037. This is not much higher than that of air (1·000) so long as this after-damp remained more than about 9° C. or 16° F. warmer than the (pure) air in the intake roads, and correspondingly more saturated with aqueous vapour, which is lighter than air, it would tend to keep along the roof. The cooled after-damp, on the other hand, would lie along the floor, forming a layer similar to that usually observed in the case of black-damp, which has about the same specific gravity.

In an actual pit explosion, it will, of course, never occur that the mixture of fire-damp and air is everywhere equable. As a rule there will be more fire-damp along the roof and less towards the floor. Moreover the air which is mixed with the exploding fire-damp will not be pure, but will contain more or less black-damp.* To illustrate this latter point, we may suppose the explosion to occur in a return airway, and that the return air has become explosive through the fan or furnace being out of order, or insufficient to cope with the gas driven out from unventilated cavities, &c., by a sudden fall of atmospheric pressure. Now, besides fire-damp, the return air of a coal mine contains a variable proportion of black-damp. In support of this statement I may quote the following analyses of return air from pits in different districts in England and Scotland.† To render the analyses more readily intelligible, they are expressed in terms of air, black-damp, and fire-damp, as well as in terms of oxygen, nitrogen, &c. By "nitrogen" is meant nitrogen + argon, the latter gas not having been determined separately.

—	Main Return, Minnie Pit, Podmore Hall Colliery, North Staffs. 19.12.94.	Main Return, No. 4 Pit, Podmore Hall Colliery. 5.1.95.	West Bullhurst Return, Talk o'th'Hill Colliery, North Staffs. 11.4.95.	South side Return, Great Fenton Colliery, North Staffs. 10.4.95.	Shaft of No. 6 Pit, Tylorstown. 25.2.96.	Upcast Shaft Burghlee and Ramsay Pits, Midlothian. 9.10.95.
Oxygen	20·30	20·31	19·77	20·31	20·27	20·50
Nitrogen	78·405	78·735	78·43	78·56	77·655	79·22
Carbonic acid	0·20 0·19*	0·30 0·31*	0·45	0·27 0·30*	0·20 0·21*	0·27 0·29*
Fire-damp	1·10	0·65	1·35	0·83 0·88*	1·87	0·00
	100·00	100·00	100·00	100·00	100·00	100·00
Air — Oxygen	20·30	20·31	19·77	20·31	20·27	20·50
Air — Nitrogen	76·80	76·84	74·79	76·84	76·69	77·56
Air — Carbonic acid	0·03	0·03	0·03	0·03	0·03	0·03
Air	97·13	97·18	94·59	97·18	96·99	98·09
Black-damp — Nitrogen	1·605	1·895	3·64	1·72	0·965	1·66
Black-damp — Carbonic acid	0·165	0·275	0·42	0·25	0·175	0·25
Black-damp	1·77	2·17	4·06	1·97	1·14	1·91
Fire-damp	1·10	0·65	1·35	0·85	1·87	0·00
	100·00	100·00	100·00	100·00	100·00	100·00

* Duplicate determinations.

From these analyses it is evident that, in the event of the return air of a pit becoming so foul that more than 6 per cent. of fire-damp was present, and the air was inflammable or explosive, the after-damp formed from an explosion would be mixed with from about 10 per cent. to 30 per cent. of black-damp. This black-damp consists of about 87 per cent. of "nitrogen", and 13 per cent. of carbonic acid, so that its composition is nearly the same as that of the pure after-damp from a fire-damp explosion with excess of air.

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* As recently shown in a paper by Mr. W. N. Atkinson and myself, black-damp is not carbonic acid, but a mixture of about 87 per cent. of nitrogen and 13 per cent. of carbonic acid. This mixture seems to be, as a rule, nothing but the residual gas left in the slow oxidation of coal by air.

† The first two of these analyses are quoted from the paper just referred to on the composition and properties of black-damp. (Trans. Fed. Inst. of Mining Engineers, Vol. VIII., 1895, p. 549.) The rest have not hitherto been published.

In the case of many fiery pits, the foul air of the main return would become extinctive to lamps or candles before becoming explosive,* and when more than 6½ parts of black-damp were present to one of fire-damp, the return air could never become explosive, although it might show a slight cap on a lamp.

The next case is that of pure fire-damp explosions, in which an excess of fire-damp is present in some portions of the explosive air, *i.e.*, more fire-damp than would suffice to consume the whole of the oxygen present. Such explosions are doubtless far more common than the first kind, because the distribution of fire-damp and oxygen in a pit is very irregular. This is partly due to the specific gravity of fire-damp being so low that it tends to accumulate in any high place, and partly to the fact that large spaces (goaves, stopped-off workings, &c.), are often charged with mixtures, varying from air containing a little black-damp, or fire-damp, or both, to almost pure fire-damp or black-damp. In illustration of this latter statement I may quote the following analyses.

No. 1. Sample of gas issuing violently from a boring into the main intake airway of Moss Pit, Harecastle, North Staffordshire. In consequence of a gobfire, followed at intervals by two small gas explosions, and by one large one, carried through the whole pit by dust, the bottom of the shafts had been filled up to stop all ventilation, and the pit left for some months to allow the heated air to cool. When a bore-hole was cautiously made into the main intake road, the accumulated gas issued at great pressure. A sample of this gas was collected and sent to me by Mr. W. N. Atkinson, Her Majesty's Inspector for North Staffordshire. (An account of the accident is given in his Annual Report for 1894) :—

Fire-damp	91·01
"Nitrogen"	5·93
Carbonic acid	3·06
Carbonic oxide	0·00
	100·00

This analysis illustrates well the result of *completely* stopping off a large area of workings in a fiery pit. The small percentage of nitrogen found was probably due to the small residue of black-damp left in the pit, and not yet completely displaced by the rapidly accumulating fire-damp. The carbonic acid seems mostly to have come off from the coal along with the fire-damp, as only about a third of the carbonic acid would be accounted for by the presence of the nitrogen, counting the latter as a constituent of black-damp.

No. 2. Gas obtained from behind a stopping in the same pit, after the main roads had been reached, and the ventilation partly re-established.

Air	Oxygen	1·80	8·61
	"Nitrogen"	7·81	
Black-damp	"Nitrogen"	31·47	34·66
	Carbonic acid	3·19	
Fire-damp			56·73
			100·00

This gas would form inflammable mixtures with air almost as readily as would pure fire-damp. The black-damp had apparently been formed by air getting in behind the stoppings.

The sample was very carefully examined to ascertain whether the fire-damp was absolutely pure methane. That this was the case follows almost certainly from the fact that in two successive determinations the contraction on explosion was exactly double the volume of carbonic acid formed.

No. 3. Gas obtained through a pipe from behind a stopping in Podmore Hall Colliery, No. 4 pit. Behind the stopping were old workings. A constant slow stream of gas was issuing at all times from this stopping, into a return air-way, so evidently a little air was getting from the intake air-ways into the old workings, where its

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* It was shown, in the paper just referred to, that a mixture of black-damp and fire-damp, when added in increasing proportions to air, may first produce an atmosphere extinctive to open lights and lamps, and then an explosive atmosphere. The same is certainly true for mixtures of after-damp, fire-damp, and air, such as occur in a pit after an explosion.

oxygen was consumed and carbonic acid and moisture formed, so that it issued as black-damp.

Black-damp	Nitrogen	78·06	89·09
	Carbonic acid	11·03	
Air	Oxygen	0·72	3·44
	Nitrogen	2·72	
Fire-damp			7·47
			100·00

When diluted with ordinary return air in the most favourable proportions, this gas might show a cap, but it could never become inflammable.

No. 4. Gas from an abandoned road, Talk o' th' Hill Colliery, 11th April, 1895.

Air	Oxygen	11·93	57·08
	"Nitrogen"	45·13	
	Carbonic acid	0·02	
Black-damp	"Nitrogen"	35·29	38·40
	Carbonic acid	3·11	
Fire-damp			4·52
			100·00

When tested with an ordinary lamp at the entrance to the road, this gas extinguished the flame without previously showing any noticeable cap. The gas had thus the distinguishing property of black-damp, but was lighter than air, the lamp being extinguished when it was raised towards the roof. The sample was collected (by the light of an electric lamp) at a point along the road, where even a Clowes hydrogen lamp was extinguished. Previously to extinction the hydrogen flame showed a very long (3 per cent.) cap.

No. 5. Gas obtained as it issued from an opening communicating with old workings in Burghlee Pit, Loanhead, Midlothian, 11th October 1895.

Air	Oxygen	13·75	65·79
	"Nitrogen"	52·02	
	Carbonic acid	0·02	
Black-damp	"Nitrogen"	29·73	34·21
	Carbonic acid	4·48	
Fire-damp			0·00
			100·00

That excess of fire-damp tends to accumulate in any high place is a fact familiar to all connected with collieries. There may be a thin layer of fire-damp, or of air containing fire-damp, running for considerable distances along the roof of a level airway. It is surprising how difficult it is to cause this gas to mix with the fresh air below, or to dislodge fire-damp from corners in a roof. The following is an illustrative case. A heading with a slight rise was being driven, and fire-damp could be heard coming off pretty rapidly from the face, though there were no blowers. To cope with this gas a wide ventilating pipe had been carried in from the intake airway, and an abundant stream of air was playing just over the heads of the men at the face. A lamp held at the ordinary level showed no trace of a cap, and from the direction in which the air-current was playing I could hardly believe that any appreciable amount of fire-damp could be present in the roof. Nevertheless, when the Manager, who was with me, slowly raised his lamp to test for gas, it was suddenly, and without the slightest previous indication of a cap, filled with flame and extinguished. The gas in this case was said to be very "sharp." A sample obtained from a pipe inserted into the coal at the same place was found to consist of—

Fire-damp	85·85
Nitrogen	9·93
Carbonic acid	4·07
Oxygen	0·15
	100·00

When fire-damp is said to be "sharp," this seems usually to signify nothing else than that the line of demarcation between the fresh air and fire-damp is very sharp. Under favourable conditions this line will be far sharper than that between a layer of pure air and black-damp, since the difference in specific gravity (about 80 per cent.) between pure fire-damp and air is far greater than that between air and pure black-damp (about 4·5 per cent.). In many cases the line of demarcation is so sharp that there can be only a very thin intermediate explosive layer. The gas above this layer will be inexplosive, on account of the presence of more than 11 or 12 per cent. fire-damp. This upper layer will burn quietly when it is in contact with fresh air below.

The facts just referred to make it evident that in most fire-damp explosions there must be, in parts of the explosion, not sufficient oxygen for complete combustion. In such a case the chemical reaction is complicated, and without further experimental data it would be difficult to say exactly what the quantities would be of the various products formed under the conditions which prevail in a pit. Instead of carbon dioxide and aqueous vapour, a variable mixture of carbon dioxide, carbon monoxide, aqueous vapour, and probably hydrogen, will be formed, and these, when mixed with about 80 per cent. of nitrogen, and any undecomposed fire-damp, will constitute the after-damp. The latter will evidently always contain less than 12 per cent. of carbonic acid, but what is of more interest in connexion with the present inquiry, is the proportion of carbon monoxide liable to be formed. There are reasons for believing that this proportion is by no means high. It is well known that in ordinary laboratory experiments it is impossible to explode, either by introducing a flame or by means of the spark yielded by the common induction coil, mixtures of air and fire-damp containing more than a very slight excess of the latter gas. The excess of fire-damp in some way prevents the explosion. A similar excess of an indifferent gas, such as nitrogen, does not exercise this influence. As the result of a recent investigation, Professor Clowes finds that mixtures containing more than 11 to 13 per cent. of methane will not explode. In experiments with natural fire-damp,[*] I have myself found that an ordinary spark would not inflame a mixture containing 11·1 per cent. of fire-damp in air, although with 10·0 per cent. a violent explosion occurred. With the latter proportion 9·34 per cent. of carbonic acid, and (according to a calculation), about 2·7 per cent. of carbon monoxide were present in the residual gas or after-damp. Hence it would seem probable that in an explosion with an excess of fire-damp, and without dust, not more than about 3 or 4 per cent. of carbon monoxide will be formed in any part of the track of the explosion. The matter, however, certainly requiries further experimental investigation, under conditions such as occur in an actual pit explosion.

The case of the after-damp from a dust explosion is, of course, by far the most important. In all the great colliery explosions the flame seems to be propagated by dust, although in some cases the firing of a small collection of fire-damp has originated the explosion.[†] Since the explosion usually passes along the intake air-ways, which are free from fire-damp, it may also be assumed that the after-damp is practically due to the explosion of dust and air alone, and not of a mixture of dust, fire-damp, and air.

The physical and chemical conditions which prevail along the track of an explosion as it sweeps along the roads of a pit are as yet by no means clear. It seems probable, however, that there is not a complete combustion of the particles of coal dust, and that what burns in the explosion is gas distilled off by these particles. After an explosion the bodies of the men (*see* above, p. 3) and the timbers (especially in places where little force has been developed) are often found encrusted with melted, or partially coked dust. The half melted particles of dust have evidently lost part of the gas which they yield on dry distillation; and, doubtless, this gas feeds the flame. Each particle will be protected against complete combustion by the absorption of heat which must occur in the process of heating and dry distillation, and the consequent impossibility of the occurrence of a sufficient rise of temperature in the particle to render complete combustion possible before the surrounding oxygen is consumed.

As to the products of combustion, there must, in the absence of experimental data (obtained under the conditions prevailing in a pit), be much uncertainty. The gas given off by the coal dust will probably somewhat resemble crude (unpurified) coal gas; most of this will probably be burnt, but an unburnt excess may remain behind to swell the volume of after-damp. Ordinary crude coal gas is a variable mixture,

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[*] Artificially prepared fire-damp usually contains hydrogen. The pit gas employed contained 88·18 per cent. of fire-damp.

[†] According to Mr. Robson's evidence, the Tylorstown explosion was probably originated by the flame from a blasting shot in the roof of a stall igniting a small collection of fire-damp, which in its turn ignited the dust.

consisting chiefly of hydrogen and methane (fire-damp), together with about 5 per cent. of carbon monoxide, 5 per cent. of higher hydro-carbons, about 2 per cent. of sulphuretted hydrogen or ammonium sulphide, and a little carbonic acid and nitrogen. The first portion of gas which comes off on distillation is said to consist, however, chiefly of methane; and the gas which burns in the explosion will probably be this first portion. If burnt in a sufficiency of air for complete oxidation, such gas would yield an after-damp containing when undiluted about 87 per cent. of nitrogen, 12 per cent. of carbonic acid, and ·2 per cent. of sulphurous acid. If diluted with half its volume of air, the mixture thus formed would still contain sufficient sulphurous acid to cause danger to life (*see* below),[*] although apart from the sulphurous acid the mixture would cause no great distress. If burnt in an insufficient supply of air (as is certainly the case in many parts of a dust explosion), the supposed mixture of gas would yield an after-damp containing, besides about 80 to 85 per cent. of nitrogen, a mixture of carbon dioxide, carbon monoxide, hydrogen, and a little sulphurous acid or sulphuretted hydrogen, and, doubtless, other gaseous or volatile products in small quantities. This mixture might, moreover, be diluted with additional gas distilled off from the coal dust by the action of the intensely hot air left behind in the moment following the explosion, and would probably be very slightly, if at all, heavier than air.

Now, it was proved both by the results of the examination of the bodies found in all parts of the pit, and from the symptoms of the rescuers, that, whatever poisonous gases or vapours existed in the coal dust after-damp at Tylorstown, the gas present in the most poisonous proportions was carbon monoxide. Hence, in many if not all parts, of the exploding mixture there must have been an insufficiency of oxygen for complete combustion. The presence of carbon monoxide in the Tylorstown after-damp was certainly not an exceptional fact. Such evidence as I have been able to collect from records of previous explosions, and from those who have themselves been in after-damp, seems to point distinctly towards carbon monoxide being present in dangerous amount in the after-damp of all great colliery explosions. Speaking of the after-damp met with in explosions in Durham, the Messrs. Atkinson record the fact that they have themselves seen rescuers fall over while the lamps were burning brightly and giving no indications of the presence of any kind of gas.[†] They also mention that some of the bodies were found beside lamps in which the oil was exhausted, as if it had burned itself out after the men were dead. These observations lead them to conclude that carbon monoxide was present. An analysis made for one of them by Professor Bedson showed the presence of 2·5 per cent. of carbon monoxide in a sample of gas collected a few days after the Usworth explosion from behind a stopping near a fire caused by the explosion. This gas might, however, as they remark, have been due to the fire. In his report on the explosion at the Hyde Colliery (near Manchester), Mr. W. N. Atkinson also records evidence of the probable presence of carbon monoxide. In Mr. Martin's report on the explosion in 1891 at Malago Vale Colliery (Bristol district), the evidence is recorded (pp. 22 and 18) of Charles Poultney, night oversman, who was overcome by after-damp, and was found by the rescuers unconscious and severely burnt by his lamp, which was still in his hands. In Mr. Martin's report (p. 8) on the Camerton explosion (Radstock district), it is recorded that Messrs. Brathwaite and Moon, the Manager and Under-manager, were overcome by after-damp, while the naked lights which they carried were unaffected. After the explosion at the Albion Colliery in 1894 several of the rescuers told me that they became weak and hardly able to stand, although their lamps were burning (*see* p. 39).[‡] There are also very many other cases recorded in which rescuers have been overcome or killed by after-damp; and the fact of after-damp being so exceedingly dangerous points strongly to the constant presence of carbon monoxide. A man carrying a lamp could never go unsuspectingly into air dangerous from deficiency of oxygen; and danger from carbonic acid, apart from deficiency of oxygen, is quite out of the question (*see* p. 15).

With a view to ascertaining whether more direct evidence was not obtainable as to the presence or absence of carbon monoxide, and the actual causes of death in colliery explosions, I have searched the medical evidence presented at a number of inquests. As a rule, however, no very serious attempt seems to have been made to ascertain the actual causes of death, beyond the evident facts that the men had

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[*] I found that crude coal gas, burnt experimentally in the laboratory, yielded a product which, even when much diluted, produced great irritation of the eyes and respiratory passages.

[†] "Explosions in Coal Mines," p. 112.

[‡] I examined the blood of one of the horses killed at this explosion, and could find with the spectroscope no signs of the presence of carbon monoxide. Probably it had been killed instantaneously, or else died in fresh air, like the horses referred to on page 6.

somehow been killed by the explosion, and that some showed no marks attributable to burning or violence. In one case, however,—that of the Elemore explosion,—the bodies were more carefully examined (by Dr. Adamson) at the request of the Coroner. The examination disclosed the fact that in a number of cases the skin and subcutaneous tissues had a pink colour, which was rightly attributed to carbon monoxide poisoning, although no spectroscopic or chemical examination seems to have been made of the blood. I am indebted to Mr. W. N. Atkinson for an account of Dr. Adamson's observations, which were published in the "Transactions of the Northumberland and Durham Medical Society, 1887." On inquiry of colliery managers and others who have assisted in recovering the bodies after explosions, I have several times been told of the pinkness of the lips and general life-like appearance of the bodies.

As there seems to be little doubt that in great colliery explosions the immediate cause of nearly all the deaths is carbon monoxide poisoning, it is of great importance to obtain some rough ideas as to the percentage which may be present in the undiluted after-damp.

In an explosion of coal gas (by this I mean, not fire-damp (CH_4), but the gas yielded on dry distillation of coal) a much higher percentage of carbon monoxide may be formed than in an explosion of fire-damp. This is shown by the analysis made by Smithells[*] of the products of combustion of methane and ordinary coal gas respectively, when these gases are burnt with a proportion of air insufficient for complete combustion, but just sufficient to render the mixture inflammable. He found that, in the combustion of artificially prepared methane under these conditions not more than 4½ per cent. carbon monoxide is found in the residual gas (after-damp), while in the combustion of coal gas 10 per cent. may be present. The gas burnt in a dust explosion probably resembles fire-damp more nearly than ordinary coal gas, but may, nevertheless, be capable of giving more carbon monoxide than fire-damp.

An explosion of coal gas with very low percentages of air, could not, however, so far as one can judge, propagate itself as a dust explosion through a pit. The rate of propagation would be far too slow to produce the necessary disturbance of the dust; and at any rate it is clear that a dust explosion is actually accompanied with such violence as can only be explained on the supposition that the proportion of gas distilled from the dust is not very much more than the most favourable proportion possible in mixtures of coal gas and air. If this reasoning be correct, one would expect to find much less than 11 per cent.—probably less than 5 per cent.—of carbon monoxide in the pure after-damp.

From other data we can with great probability assign a minimum percentage to the carbon monoxide. A lamp or candle will not continue to burn unless at least 17·3 per cent. of oxygen be present in the air (*see* p.   ). Hence the presence of about one-sixth part of pure after-damp would render the air just extinctive. Not more than a sixth of after-damp can thus be present in the air which is fatal to the men in cases where lamps are found still burning beside the bodies (*see* Appendix A.). Now there must, apparently, be at least 0·3 per cent. of carbon monoxide in this air (*see* p. 17). Hence there must be at least $\cdot 3 \times 6 = 1 \cdot 8$ per cent. of carbon monoxide in the undiluted after-damp. It does not seem likely that there is very much more, otherwise accidents to rescuers (who have no certain guide but their lamps) would probably be much more frequent than is actually the case, and men would more often be found dead with their lamps burning.[†] On the whole it seems probable that undiluted after-damp contains about 3 per cent. of carbon monoxide on an average. Undoubtedly, however, there may be either a higher or a lower percentage, according as the conditions vary in different parts of the explosion.

THE ACTION on MEN and LAMPS of the GASES PRESENT IN, OF MIXED WITH, AFTER-DAMP.

To understand the dangers to life after a colliery explosion, and the possibilities of escaping these dangers, it is necessary to have a clear idea of the action both on men and lamps of the gases which are likely to be present in the air of the mine. These gases, so far as is known, are carbon dioxide, carbon monoxide, nitrogen, fire-damp, and sulphurous acid. Oxygen may be deficient or absent.

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[*] "Transactions, Chemical Society," Vol. LXI., 1892, p. 211.

[†] Even in South Wales, where explosions are relatively frequent, it does not seem to be at all generally known that air mixed with after-damp may be poisonous, although a lamp still burns in it.

1. *Carbon Dioxide.*

Carbon dioxide (or carbonic acid) when present in great excess, is a distinctly poisonous gas. It does not act, as sometimes stated, by merely diluting the oxygen of the air. Air mixed with 50 per cent. of carbon dioxide causes rapid death, while air mixed with an equal proportion of nitrogen has very little effect. As shown above, however, there can never be more than about 12 per cent. of carbon dioxide in after-damp, and in practice it can seldom or never occur that even this moderate percentage is present. In breathing air containing increasing proportions of carbon dioxide, the first distinct effects are felt with about 3 or 4 per cent. The respirations become somewhat deeper, but nothing further is experienced. Animals may be kept for weeks in such an atmosphere without apparently suffering inconvenience.* The respirations increase with the percentage, both in frequency and depth, until with about 6 per cent. there is distinct panting. At the same time slight frontal headache may be felt, which often increases for a short time when fresh air is again breathed. At 7 or 8 per cent. the panting is very distressing, especially at first, and with 10 or 11 per cent. the respiratory distress is extreme. With a somewhat higher percentage an anæsthetic action seems to occur, so that consciousness is benumbed or entirely lost, although life may not be endangered, at least for many hours, judging from experiments on animals.

The action of air containing carbon dioxide on lights (candles, lamps, &c.) seems to depend almost entirely on the reduction of the oxygen percentage which accompanies the dilution of the air with carbon dioxide. According to Professor Clowes† an atmosphere containing about 15 per cent. of carbon dioxide extinguishes lights. Air diluted with 17 per cent. of nitrogen has the same effect (*see* below). I have myself found that a light (candle) will burn in a mixture containing 75 per cent. of carbon dioxide if 25 per cent. of oxygen be present at the same time. Contrary to what is often stated, carbon dioxide has thus very little specific action in extinguishing flames.

2. *Nitrogen* (*Deficiency of Oxygen*).

Nitrogen‡ has no specific action on men or animals. When added to air it only acts indirectly by diminishing the oxygen percentage. Other physiologically indifferent gases (such as hydrogen) have the same indirect action. When the oxygen percentage of air is gradually reduced by absorption of the oxygen, or (what is exactly the same thing) by addition of nitrogen, very little may be felt before the occurrence of impairment of the senses and loss of power over the limbs. If the reduction is gradual, and the symptoms be carefully watched, it will be noticed that at about 12 per cent. of oxygen (*i.e.*, with a reduction of 9 per cent.) the respirations become just perceptibly deeper. At 10 per cent. the respirations are distinctly deeper and more frequent, and the lips become slightly bluish. At 8 per cent. the face begins to assume a leaden colour, though the distress is still not great. With 5 or 6 per cent. there is marked panting, and this is accompanied by clouding of the senses and loss of power over the limbs, which would probably end sooner or later in death. It is probable that any sudden exertion made in air markedly deficient in oxygen may lead to temporary loss of consciousness, so that sudden efforts should be avoided in all cases where, through accident or necessity, a man is in an atmosphere which will not support a light, and in such a position that he might fall into worse air or otherwise injure himself. When air containing less than 1 or 2 per cent. of oxygen is breathed, loss of consciousness, without any distinct previous warning symptom, occurs within about 40 or 50 seconds. Loss of consciousness in air deprived of oxygen is more rapid than in drowning or strangling, since in the former case not only is the supply of fresh oxygen cut off, but the oxygen previously in the lungs in rapidly washed out. Loss of consciousness is quickly succeeded by convulsions, which are followed by cessation of the respirations. The heart still continues to beat, in the case of cats and dogs, for from two to eight minutes; in man this period is probably longer, for it seems to be a general rule that the larger an animal is the longer it will resist asphyxiation. I have myself breathed for half a minute without loss of consciousness an atmosphere (containing 0·7 per cent. of oxygen) which, within 15 seconds, produced

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* An account of experiments on the action of carbonic acid and want of oxygen on men, animals, and lights, is given by Dr. Lorrain Smith and myself in the "Journal of Pathology and Bacteriology," Vol. I. (1892), p. 168.

† "Transactions, Federated Institution of Mining Engineers," Vol. VII., p. 420.

‡ Including argon.

in a mouse not merely loss of consciousness, but convulsions, followed by almost complete cessation of the respiratory movements. So long as the heart is beating, however feebly, animation may be restored by artificial respiration. This may require to be continued for a considerable period, as the after effects of deprivation of oxygen are very serious, and the respiratory centre may not recover for some time. After the breathing has been re-established consciousness may not return for many hours, and very careful treatment may be required to avert death at a later stage.

Candles or safety lamps are extinguished when the percentage of oxygen falls to from 17·6 per cent. to 17·1 per cent.[*] An upright tallow dip goes out at about 17·6 per cent. of oxygen, but by holding it horizontally and spreading out the wick it may be made to burn until the percentage is reduced to 17·1 per cent.

3. *Black-Damp.*

As already mentioned, black-damp is not a pure gas, but a mixture containing about 87 per cent. of nitrogen and 13 per cent. of carbon dioxide. The action on men and lights of air contaminated with black-damp follows from what has been already said. The dangers to life arising from black-damp evidently depend on the reduction which it causes in the oxygen percentage of the air. On the other hand, a simple calculation will show that before any real danger can occur the carbonic acid will, by causing severe panting, have given distinct warning of the impending danger.[†] It should be distinctly understood that excess of carbonic acid produces panting far more rapidly than does a corresponding deficiency of oxygen; and that with carbonic acid the panting begins long before there is serious danger, while panting from deficiency of oxygen hardly occurs until danger is imminent. The presence of the carbonic acid in black-damp thus gives a valuable and timely warning of approaching danger.

It follows from what has been said above that an atmosphere which has been rendered just extinctive to lamps from admixture with nitrogen or black-damp is harmless to men. In case of urgent necessity a man may penetrate without harm into an atmosphere containing four times as much black-damp as would extinguish a lamp. Any such attempts should, however, be made with the utmost caution, as a man who falls in air containing black-damp will almost certainly fall into worse air. The flame of a Clowes hydrogen lamp, when adjusted for testing for fire-damp, is extinguished in air containing about 10 per cent. of oxygen or 52 per cent. of black-damp. If fire-damp be present extinction occurs earlier.

4. *Fire-Damp.*

The action on man of methane, or fire-damp, is exactly the same as that of nitrogen. In other words fire damp only acts by diluting the oxygen of the air.[‡] It follows from this that air containing as much as 50 or 60 per cent. of fire-damp may be breathed for a time without harm, although about 5 per cent. will extinguish a safety lamp. Nevertheless much caution is required in going into air containing much fire-damp; for instance, in ascending an incline for the purpose of restoring the ventilation in workings charged with fire-damp. The danger lies in the fact that the percentage of fire-damp is apt to increase very rapidly up an incline, and before he falls, a man may have got into an atmosphere which, even on the floor of the incline, contains not enough oxygen to support life. This danger may be avoided by going very slowly, and with a companion a few feet behind. It occasionally happens that fire-damp is mixed with traces of sulphuretted hydrogen. This is easily recognised by the smell of rotten eggs. Sulphuretted hydrogen is excessively poisonous; as little as 0·1 per cent. will cause rapid loss of consciousness and death. Smarting of the eyes and catching of the breath are signs of imminent danger from this gas.

5. *Carbon Monoxide.*

This gas is present in after-damp, smoke, and "gobstink" (*i.e.*, the mixture of gases given off from coal which has spontaneously heated). It differs from other poisonous gases in its particularly slow and insidious action, and to render this action intelligible

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[*] Some very careful experiments on this point were made by Mr. W. N. Atkinson and myself at Lilleshall Colliery ("Transactions, Federated Institution of Mining Engineers," Vol. VIII, 1895, p. 558), and I have since then frequently verified the data there obtained. More extended observations on the same subject have been carried out by Professor Clowes ("Proceedings, Royal Society," Vol. LVI., 1894, p. 4).

[†] Direct experiments on these points are described in a paper by myself in the "Proceedings of the Royal Society," Vol. 57, p. 249.

[‡] *See* "Transactions, Federated Institution of Mining Engineers," Vol. VIII., p. 556.

some explanation is necessary. The oxygen absorbed from the air in the lungs is normally taken up by the blood in the form of a loose chemical combination with the red colouring matter (hæmoglobin) of the corpuscles; and so carried by the circulation to the tissues, where it is used up. The hæmoglobin not only combines with oxygen, but also forms a much more stable compound with carbon monoxide, and, as was shown by Claude Bernard, hæmoglobin which is saturated with carbon monoxide cannot take up oxygen. Hence, when the blood of a living animal is saturated with carbon monoxide no oxygen can be conveyed by the hæmoglobin from the lungs to the tissues, and death must occur from want of oxygen. Carbon monoxide has no other effects than those caused by interference with the oxygen supply to the tissues.* Apart from its property of combining with the hæmoglobin it is a physiologically indifferent gas like nitrogen. The symptoms produced by it are therefore essentially the same as those described above as due to partial or complete absence of oxygen in the air breathed.

The key to the peculiarly insidious action of carbon monoxide is afforded by the following two facts. (1.) The affinity of carbon monoxide for hæmoglobin is a very powerful one, so that even when a very small percentage of it is present in the air, absorption by the blood may go on, steadily, though slowly, until finally the oxygen carrying power of the hæmoglobin is reduced to a dangerous extent. (2.) The symptoms produced by deficiency in the oxygen supply to the tissues are, as already remarked, very slight up to the point at which there is loss of power over the limbs. When the limbs completely fail, it is, of course, impossible for a man to get out of the poisonous atmosphere.

The affinity of carbon monoxide for hæmoglobin is about 250 times as great as that of oxygen. In other words, the hæmoglobin of blood brought into contact with air containing about 0·1 per cent. of carbon monoxide will finally become about equally saturated with carbon monoxide and oxygen. If the same blood be afterwards brought into contact with pure air, constantly renewed, the carbon monoxide is gradually driven out. This process of driving out occurs about five times as fast in pure oxygen (which contains about five times as much oxygen as air). When the blood of the living body has become about 50 per cent. saturated with carbon monoxide there is loss of power over the legs.

These facts make it possible to understand the process of gradual poisoning, or of recovery in fresh air. With less than 0·1 per cent. of the gas in the air the blood does not become more than 50 per cent. saturated, so that even a prolonged exposure does not cause complete helplessness. With 0·2 per cent. the blood will become about 67 per cent. saturated, and complete helplessness, with loss of consciousness, would doubtless occur. Probably this percentage would finally cause death, from the gradual damage produced by the diminished supply of oxygen to the tissues. 0·30 per cent. would certainly cause death in time.

It is of great practical importance to know the times required for dangerous symptoms to develope in atmospheres containing carbon monoxide, as the necessity often arises of going temporarily, for rescue or other purposes, into such atmospheres. The times required may be roughly calculated as follows. The blood of a man will take up about two pints (1·1 litres) of carbon monoxide or oxygen. Hence about one pint of carbon monoxide must be absorbed to produce half saturation of the blood. Now a man at rest breathes about 10 or 12 pints of air in a minute, and experiment shows that of the carbon monoxide inhaled about 60 per cent. is absorbed. Supposing, therefore, that the air contained 0·1 per cent. of carbon monoxide, he would absorb about $\frac{7}{1000}$ ths of a pint per minute. It would thus take him nearly $2\frac{1}{4}$ hours to absorb a whole pint. A man who is walking breathes, however, about three times as much air as a man at rest. Hence he might perhaps absorb a pint within an hour. With 0·2 per cent. of carbon monoxide the time would be half as long, with 0·3 per cent. a third as long, &c. For a man who had already been in the poisonous atmosphere, and whose blood had not recovered, the interval of safety would be correspondingly less than in the case of a perfectly fresh man. Hence, in any case where it is necessary to work in an atmosphere suspected of carbon monoxide, men should, so far as possible, be kept in reserve in fresh air. It was through the adoption of this precaution that the lives of Mr. Thomas and his fellow rescuers were not sacrified after the Tylorstown explosion (p. 7.) Had the whole party advanced together, none might have escaped.

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* The experimental evidence on which this and many of the other statements made below are based, is contained in papers by myself in the "Journal of Physiology," Vol. XVIII. (1895), pp. 200, 430, and 463.

The danger of advancing far along passages containing after-damp, smoke, gobstink, &c., is very evident, since a man may go a long way before he feels the effects of the carbon monoxide, and when he does feel them he may be quite unable to escape.

Certain symptoms occur before the stage of complete helplessness is reached, and these symptoms should be carefully noted. The first and most important signs of the accumulation of carbon monoxide in the blood are dizziness, weakness in the legs, dimness of sight, and palpitation following any extra exertion, such as lifting a heavy weight, ascending a steep incline, or running. These symptoms become quite distinct when the blood is about 25 to 30 per cent. saturated. As the saturation increases, the symptoms become more and more marked, until finally, at about 50 per cent. saturation, the limbs are so weak that any effort to walk causes them to give way entirely.

Very little actual distress accompanies the action of carbon monoxide. After paralysis of the limbs the senses are gradually more and more benumbed, as by a gentle anæsthetic. If the percentage of carbon monoxide is large (more than 1 or 2 per cent.) loss of consciousness is followed by convulsions, &c., as in suffocation from rapid deprivation of oxygen. If there is less than 1 per cent. of carbon monoxide death is very gradual and peaceful. The positions in which bodies are often found after an explosion show clearly that this is actually the case.

Men who have been for some time unconscious from carbon monoxide poisoning, or, what is essentially the same thing, want of oxygen, but who have been afterwards rescued, may suffer for many days or weeks from after symptoms of a most formidable character. Appendix II. contains a report, drawn up by Dr. Shaw Lyttle, Medical Officer to the Albion Colliery, of the after symptoms of men rescued after the explosion at that colliery in 1894. I myself went to the colliery four days after the explosion, and saw many of the men referred to in this Report. A man who has been only partially disabled by carbon monoxide, or who has only been helpless or unconscious for a short time, will usually recover completely within a few hours. Recovery is accompanied by very severe headache, and often by nausea and vomiting. The headache and nausea seem to be more severe the longer the exposure. I have myself found that an exposure of several hours to as little as ·07 per cent. of carbon monoxide will cause not merely dizziness, &c., on exertion at the time, but a headache afterwards, lasting for about 12 hours.

From experiments on myself I calculated that about six hours are required for the carbon monoxide to disappear entirely from the blood in severe cases of poisoning. In the case of one of the men rescued at Tylorstown, I examined the blood about 24 hours after his removal from the pit, while he was still absolutely helpless and almost unconscious. No carbon monoxide could be detected with the spectroscope. He was found still alive beside the bodies of several other men (Nos. 33, 34, 35, and 38), who had died of carbon monoxide poisoning. It seems probable that after an hour or two in fresh air so much of the carbon monoxide will have left the blood that the normal oxygen supply to the tissues will be re-established. The mistake is often made of attributing what are really after effects to the continued presence of carbon monoxide in the blood.

In more severe cases recovery is much less certain, is very gradual at the best, and is accompanied by symptoms indicative of serious damage which the nervous system has sustained during the period of deprivation of oxygen. Consciousness is for long absent. The breathing may be shallow and irregular, or deep and stertorous. The pulse may be almost imperceptible at times. The temperature frequently rises after a time to 103° or higher. There are usually signs of very abnormally increased reflex excitability of the trunk and limbs, the least attempt to move the arms, legs or body giving rise to violent contractions of the muscles, or even to epileptiform seizures. The latter may even occur spontaneously. These symptoms resemble very closely the effect of strychnine poisoning, and are fully described in Dr. Lyttle's Report. In the case of the man referred to above, the same increased reflex excitability was observed by Dr. Morris, who found it very difficult to carry out artificial respiration under the circumstances. Similar symptoms have been observed by Böhm[*] in the case of animals which had been partially asphyxiated by hydrogen or by occlusion of the trachea; also in poisoning by sulphuretted hydrogen in a case which I recently described.[†] The symptoms in question are thus not peculiar to carbon monoxide poisoning.

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[*] Archiv für experimentelle Pathologie, Vol. VIII., p. 68.

[†] "Poisoning by sewer gas," "Lancet," January 29th, 1896, p. 220.

As recovery progresses, clear consciousness and power over the limbs are very gradually restored. Partial paralysis of some parts of the body may remain for a time. At first there is great slowness in understanding questions, or carrying out any movement. All memory of the explosion or exposure to the poisonous atmosphere may at first be lost, and it is only after many days, or weeks, that the normal vigour of mind and body return.

A few remarks may be of use as regards the treatment of carbon monoxide or after-damp poisoning. There is no doubt that just at first the administration of oxygen would be of service in rapidly clearing the blood of carbon monoxide.* In a pit, however, oxygen will not be available unless special apparatus has been provided for rescue purposes, and by the time a man has been brought to the surface, oxygen will probably be of little use. If the air be not free of after-damp, the man should be removed at once to a safe position. Artificial respiration should be employed as long as the breathing is at all shallow or irregular. If the pulse is feeble, stimulants should be given. Hypodermic injections of ether were found by Dr. Morris to be of great service. The first effect of cool fresh air seems, for some reason or other, to be somewhat dangerous. After the Albion Pit explosion it was noticed that some of the rescued men seemed to lose consciousness on being brought to the fresh air (see p. 37). Mr. Chrystle, Manager at the Oldfield Colliery, North Staffordshire, informs me that in dealing with a gobfire he observed that men who were affected by the gas from the heated coal immediately got worse, or even lost consciousness, if they went into an intake air-way to rest. From the symptoms which he described there could be no doubt that the poisonous gas was carbon monoxide. He himself lay unconscious for a long time in the air-way, the temperature of which was about 10° Fah. lower than that of the level on which the men were working. The explanation of the bad effects of the current of cool air is not altogether clear. Possibly the cold in some way diminishes the blood supply to the brain, or perhaps the temperature of the body is reduced owing to impairment of the heat-producing or heat-regulating functions. In the case of small animals poisoned by carbon monoxide, heat production is much diminished, the body becomes very cold, and recovery in fresh air is very much hastened by artificial warmth. The application of artificial warmth is probably often a matter of much importance at first in the treatment of carbon monoxide poisoning. Dr. Morris employed hot water bottles and blankets in bringing out the man referred to above, and this seemed to be of great service.

The treatment in their own houses of the men who have been got out of the pit alive after an explosion is often very difficult on account of the absence of skilful nursing. Their chances of recovery are certainly much diminished from this cause. It is of great importance that everything should be done to meet every symptom (such as rise or fall of temperature) as it arises, and to promote rest; and thus give the injured nervous system the best chance of recovery. Any burns or injuries should be attended to with special care, and every source of disturbance or discomfort carefully avoided or removed. It is to be feared that many men who have been rescued from explosions have afterwards died from want of proper nursing, and this matter deserves careful consideration.

The recognition of carbon monoxide in the air of mines is a matter of much practical importance, and many lives have been lost through ignorance of the fact that the lamps, to which miners trust for the recognition of other gases, give no *direct* indication of carbon monoxide. Like other explosive gases, it shows a cap on an ordinary flame if present in a higher proportion than about 1 per cent; but in after-damp and gobstink carbon monoxide always occurs in combination with such an excess of nitrogen that the lamp is extinguished before it can show a cap. As shown above (p. 16), when more than 16 per cent. of after-damp, or about 0·5 per cent. of carbon monoxide is present, a lamp will be extinguished. Hence the indications of a lamp will, at least, prevent a man from going into an atmosphere which is very rapidly poisonous from carbon monoxide. Nevertheless it is clear that some better indicator is required. When daylight is available as little as ·01 per cent. of carbon monoxide in air may be detected, and roughly estimated by the eye by means of the colour-test, which I have recently described. This test would not, however, be available on the spot in the pit, on account of the bad light. There, is, however, another method, which would, I feel confident, be practically successful. In small animals the rate at which the blood becomes saturated with carbon monoxide is far more rapid than in man; hence a small animal, such as a mouse, shows the effects of the gas far more

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* Journal of Physiology, Vol. XVIII., (1895), pp. 201 and 457.

rapidly than a man, although a given percentage of it seems not to be, in the long run, more poisonous to a mouse than to a man.* Practically speaking, the condition of a mouse which has been for a very short time in a poisonous percentage of carbon monoxide, indicates what will be the condition of a man carrying it after a much more prolonged stay in the same atmosphere. With a man at rest it takes about 20 times as long for the man as for the mouse to be distinctly affected by the gas. Thus, to take an example, I found that with ·4 per cent. a mouse was distinctly affected in one and a half minutes, and quite helpless in three minutes, while I myself was not distinctly affected until after half an hour. The air I was breathing contained about the same percentage as is so often fatal to rescuers. These experiments show distinctly how valuable the indications given by a mouse, or other small animal, would be to men exposed to danger from after-damp. The mouse may be carried in a small cage, or a lamp chimney closed at the ends with wire gauze. When dangerous percentages of carbon monoxide are encountered the mouse will begin to pant, and show signs of weakness in the legs; should the mouse suddenly become unconscious, danger is imminent. A few white mice might easily be kept in the engine room of the winding engine, or in stables or other places in the pit.

The post mortem appearances actually found in cases of carbon monoxide poisoning are described in Appendix A. The recognition of the cause of death depends on examination of the blood, and a few details on this subject may be of service to medical men. The blood is diluted with water in a test-tube until the two absorption bands (of oxy- or carboxy-hæmoglobin) are most clearly visible. A drop or two of ammonium sulphide are now added, and the solution slightly warmed. If the two bands are not now replaced in the usual way by the single band of reduced hæmoglobin, carbon monoxide is present. This test is not a very delicate one, and for the following reasons. In the first place, the two bands of carboxy-hæmoglobin. although they occupy nearly the same position as those of oxy-hæmoglobin, are not nearly so well-defined. Secondly, the bands are in such a position that the luminous space between them becomes filled by the single absorption band of reduced hæmoglobin when the latter is present. Hence, when the blood is less than about 40 per cent. saturated with carbon monoxide, the test becomes useless, since the double bands are no longer, even dimly, visible in the reduced blood.

The colorimetric test employed in the analysis described in Appendix A., may be employed in a simple form as follows: A drop of the blood is diluted with about 100 times its volume of water: For purposes of comparison, a solution of about the same *depth* of colour is prepared from normal blood (obtained from a prick of the finger, or from the butcher). Part of this solution is saturated with coal gas, which will alter the tint from yellow to pink. The three solutions are then poured into the narrow test-tubes of equal diameter, and compared. If the *depth* of colour of the first solution now appears to be greater than, or less than, that of the other two solutions, water or blood must be added (to the first solutions) until equality is established. The tints of the three solutions are now compared. According to the percentage saturation of the sample of blood under examination, the tint of the first solution will approach to that of the normal blood, or the blood saturated with coal-gas (*i.e.*, with carbon monoxide), and a rough estimate may be made of the percentage saturations. This test is both simpler and much more delicate than that with the spectroscope, but cannot be carried out in artificial light.

The coloured plate is a representation of the tints actually observed. A. is a solution of normal blood; B. of the same blood well shaken with coal-gas, and C. of blood from body No. 12.†

In undiluted blood examined in bulk, the peculiar tint, due to the presence of carbon monoxide, can hardly be recognised. Blood saturated with carbon monoxide is bright scarlet, like arterial blood. The blood from the body of a man directly killed by carbon monoxide has a dark purplish red colour, like that of ripe Morella cherries. The darkness of colour is due to admixture of reduced hæmoglobin with the carboxy-hæmoglobin. If the corpuscles have been dissolved by putrefactive changes, the dark colour will be much more accentuated. The characteristic appearances are in the tissues and organs, which are pink or red when examined the moment they are cut into. A red colour seen after exposure to the air might be due to the formation of oxy-hæmoglobin. Further details as to the percentage saturation of the blood will be found on page 23.

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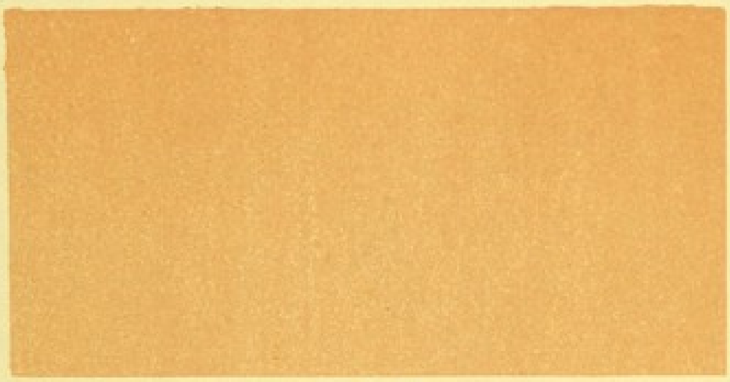
* Journal of Physiology, Vol. XVIII. (1895), p. 447.

† The original sketch was kindly made for me by Mr. E. W. Pilcher.

Nº 1

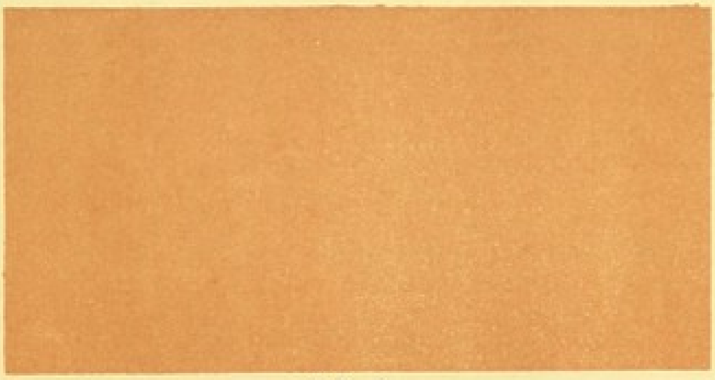
Normal Blood.



Nº 2

Blood from Body.

Nº 12.



Nº 3.

Normal Blood saturated with
Carbon Monoxide.

To be looked at by day light.

Wyman & Sons Ld. Lith. 63, Carter Lane. 6234 4.96

Sulphurous Acid.

As it seems probable that sulphurous acid is present in after-damp, and causes the well-known irritation of the eyes and air passages, some acount of its action is desirable. According to Lehmann[*] as little as ·001 per cent. produces slight irritation of the respiratory passages. With ·003 per cent., the symptoms of irritation are very marked. Ogata[†] found that ·04 per cent of the gas caused dyspœa and signs of inflammation in the eyes and air-passages in rabbits and other animals. About 0·1 per cent. was sufficient to cause death after some time. Sulphurous acid is thus an exceedingly poisonous gas; but the symptoms of irritation caused by it seem to occur long before there could be any danger to life. Its presence in after-damp, therefore, affords a valuable indication of danger.

Sulphurous acid, when breathed in poisonous proportions, causes decomposition of the hæmoglobin, so that the two absorption bands shown by the spectroscope in diluted blood become finally much less visible than usual. Bearing in mind the possibility that poisonous proportions of sulphurous acid might be present in after-damp, I carefully examined the blood for evidences of decomposition of the hæmoglobin (*see* Appendix A., p. 37). Although the hæmoglobin seems to be slightly decomposed, this condition could not have materially contributed towards death. There was also no distinct indication of irritation of the air-passages in the dead horses; and a survivor, whose lungs I carefully examined about 30 hours after the explosion, had no symptoms of bronchitis or pneumonia, although he was still almost unconscious, and must have been exposed for long to the after-damp.

For purposes of convenience I have drawn up the following tables, showing the effects of different gases on men and lights. Except in the case of the figures for oxygen, the percentages indicated are percentages by volume in a mixture of the gas and pure air. The figures for oxygen represent the percentages of oxygen present in a mixture of air and pure nitrogen) or air partly deprived of its oxygen).

TABLE I.

Oxygen.			Carbon Dioxide.			Carbon Monoxide.	
Percentage Present.	Effects on Man.	Effects on Lights.	Percentage Present.	Effects on Man.	Effects on Lights.	Percentage Present.	Effects on Man.
17·3	Nil.	Extinguished.	3·5	Breathing deeper.	Still burns.	·05	After half-an-hour or more giddiness on exertion.
12	Breathing slightly deeper.	,,	6	Marked panting.	,,	·1	After half-an-hour or more inability to walk.
9	Breathing deeper and more frequent. Face bluish.	,,	10	Severe distress.	,,	·2	After half-an-hour or more loss of consciousness; and, perhaps, final death.
5	Loss of consciousness and final death.	,,	15	Partial loss of consciousness.	Extinguished.	1	After a few minutes loss of consciousness; and final death.
0	Death, with convulsions	,,	25	Final death.	,,		

TABLE II.

Black-damp (containing 87 per cent. Nitrogen and 13 per cent. Carbon Dioxide.			Fire-damp (or Methane).			After-damp (containing 3 per cent. of Carbon Monoxide).		
Percentage Present.	Effects on Man.	Effects on Lights.	Percentage Present.	Effects on Man.	Effects on Lights.	Percentage Present.	Effects on Man.	Effects on Lights.
16	Nil.	Extinguished.	1	Nil.	First indication of a cap.	2	After half-an-hour or more slight, giddiness on exertion.	Nil.
28	Breathing slightly deeper.	,,	2	,,	Well formed cap.	3·5	Inability to walk.	,,
50	Severe panting.	,,	5·5	,,	Lamp fires and goes out.	7	Loss of consciousness.	,,
66	Life endangered.	,,	45	Breathing slightly deeper.	,,	10	Death.	Burns rather dimly.
			70	Life endangered.	—	16	,,	Extinguished.

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[*] Archiv. für Hygiene, Vol. XVIII. (1893), p. 180.

ACTION OF AFTER-DAMP, HEAT, AND VIOLENCE, ALONG THE TRACK OF AN EXPLOSION.

I.—*After-damp.*

From the data given above it is evident that after-damp might cause death, either from deficiency of oxygen or from the presence of carbon monoxide. If the after-damp were quite free from air or oxygen, it could make no difference whether carbon monoxide were present or not, since carbon monoxide has the same action as deficiency of oxygen. It is thus theoretically quite conceivable that the blood might become saturated with carbon monoxide, and that yet the presence of this gas should have no influence in hastening death.

Practically, however, there can be no doubt that in the Tylorstown explosion the cause of death was in nearly every case carbon monoxide poisoning, and not want of oxygen. When death occurs from absence of oxygen in the air the appearances met with are marked blueness of the face, lips, tongue, &c., with distention of the veins of the neck and part of the chest. If carbon monoxide be also present in the suffocative atmosphere the blue colour is nevertheless not replaced by a distinct red. Death occurs before the venous blood has time to become saturated with carbon monoxide. This, at least, is the case with animals. The following are the notes of the appearances presented by the body of a mouse killed by sudden immersion in pure coal gas (which contains about 5 per cent. of carbon monoxide, and practically no oxygen):—

Legs pale, but bluish. Tongue blue, nose and lips dusky pink. Skin about anus blue. Skin at root of ears blue. On section, colour of blood in intestines reddish blue. Large veins of abdomen distended with blue blood. Liver congested with pinkish blue blood. Lungs bright pink. On examination of the blood in dilute solution, hæmoglobin of liver, kidneys, and of blood from inferior vena câva found to be about one-third saturated with carbon monoxide. Hæmoglobin from spleen free from carbon monoxide. Hæmoglobin from lungs apparently fully saturated, but a satisfaatory specimen could not be obtained.

The blood in the veins and most of the organs thus becomes only very partially saturated in cases of suffocation by gas containing carbon monoxide but no oxygen.

This fact is probably the explanation of the extraordinarily rapid recoveries sometimes observed in cases of acute poisoning by coal gas. As soon as the coal gas is removed from the lungs, and a plentiful supply of oxygen or air substituted for it, the unsaturated venous blood still slowly entering the lungs takes up oxygen abundantly, and so causes rapid recovery as soon as it reaches the tissues. A striking case of this kind was recorded by Colonel Elsdale in the *Nineteenth Century*, Vol. 29 (1891), p. 719.

Except Nos. 19 and 21, none of the bodies of men killed by after-damp at the Tylorstown explosion showed the appearances just described. Hence it follows that oxygen sufficient to support life must have been left in the air-ways all along the track of the explosion At the very least 5 per cent. of oxygen or 25 per cent. of pure air must have been present. This discovery came to me as an entire surprise. I had previously thought that as carbon monoxide is present in the after-damp, all the oxygen of the air must certainly have been used up, and that men in the track of the explosion must be killed by the absence of oxygen, if not by other causes. On further inquiry, other evidence was obtained of the presence of oxygen, even immediately after the passage of the flame. After the explosion a small fire was discovered near the face in a part of the No. 8 pit, traversed by the explosion. The fire had evidently been caused by the ignition by the explosion of a small blower at the face, and consequent secondary ignition of the coal. Now, according to Professor Clowes' observations, a fire-damp flame is extinguished at about the same oxygen percentage as a candle or lamp. Hence there must apparently have been, even just after the passage of the flame, about 17 per cent. of oxygen at this place. At other places in the same pit there was evidence of timber and brattice cloths having been burning for a time after the explosion, and in one place a man's cap was found burnt. None of these objects could have burned without the presence of a large amount of pure air—probably not less than 80 per cent.—immediately after the explosion. In other explosions evidence of the same kind is constantly presented. Fires or signs of burning along parts traversed by the flame seem to be met with frequently by explorers, and the fires are a source of danger, from the risk of their causing explosions when fire-damp accumulates in parts beyond them. These fires would, perhaps, be much more frequent were they not blown out by the blast of after-damp, or drowned out by the shower of coal dust, small coal, &c., following the explosion. It would probably be safe to assume from the above evidence that at least 50 per cent. of air is on an average contained in the after-damp along the traversed air-ways just after the explosion, and that at places there is 80 per cent. or more of pure air. The presence of so much air may be accounted for in several ways. It seems probable that in the dust-cloud, which is raised in the front of the explosion wave, there is in parts more dust present than can be heated to the ignition point (*see* p. 25). In other places, perhaps, not enough dust may be present to give gas sufficient for the complete consumption of the oxygen. The oxygen left unconsumed from these causes will soon be augmented by air carried in by convection currents from adjoining air-spaces, or sucked in as the after-damp cools, and its moisture condenses.

If the pure after-damp is diluted with from 50 to 80 per cent. of air, the mixture thus formed will not contain more than about 1·5 to ·6 per cent. of carbon monoxide. The distribution of the saturated blood in the blood vessels seems to correspond well to this conclusion. Heger has shown that in rapid death from poisoning by relatively large percentages of carbon monoxide the blood of the spleen does not show the presence of carbon monoxide when examined with the spectroscope. Death produced in this way is thus so rapid that, as in suffocation by coal gas, the venous blood has not time to become saturated with carbon monoxide. The sudden deprivation of oxygen, caused by the carbon monoxide poisoning, leads to reflex blocking of the circulation, just as in suffocation caused by simple deprivation of oxygen; and this blocking keeps the venous blood from becoming highly saturated with carbon monoxide before death.

Now, in the samples of venous blood from bodies Nos. 12 and 44, the saturation of the hæmoglobin was in each case 79 per cent. This is a very high saturation, such as one could only expect to find in cases where a very low percentage of carbon monoxide had caused death. In the case of No. 12, death was known to have occurred in very dilute after-damp, since the body was not scorched, and was lying beside a lighted lamp. Not more than a sixth of after-damp can thus have been present. No. 44, on the other hand, was covered with coal-dust, and scorched all over, and had the mouth coated with coal-dust. Hence, in this case, there had evidently been exposure to the full blast of the explosion. As, however, the saturation reached by the blood was exactly the same as in No. 12, the percentage of carbon monoxide in the air can hardly have been very different in the track of the explosion and in the place where the lamps still burned in the poisonous air. The high saturation of the blood in No. 44 was not exceptional. It seemed to be the general rule that in all cases where there was much evidence of burning the carmine-red colour of the blood was exceedingly marked.

In the case of the horses examined, the saturation of the hæmoglobin with carbon monoxide was very high, and exactly the same in the right and left ventricles. This fact seems to afford strong evidence that death took place in air containing a very low percentage of carbon monoxide. The same inference seems to follow from the fact that the blood of the spleen, although it looked dark in many cases, turned out on analysis to be nearly as highly saturated as the blood elsewhere. This is shown in the case of horse No. 6, where the blood of the spleen looked very dark, and was therefore specially examined.

As the percentage of carbon monoxide in air along the direct track of an explosion is a matter of much practical importance, I have made several observations on the bodies of animals killed in air containing varying percentages of carbon monoxide, with a view to ascertaining the post mortem appearances corresponding to each percentage.

I. Mouse introduced into air containing 3·6 per cent. of carbon monoxide.

Animal became unconscious and fell over in about 15 seconds. Convulsions in 20 seconds. All movements had ceased in 1¼ minutes.

On post mortem examination, skin of legs, &c. pale, but reddish-blue when any colour visible. Tongue and lips congested and dusky reddish-blue. Liver and kidneys reddish-blue and congested. Blood from liver and from abdominal veins about 60 per cent. saturated with carbon monoxide. With spectroscope, carbon monoxide bands only dimly visible, after reduction of the blood solution with ammonium sulphide. On comparing the solution in water with one of corresponding density of colour from the blood of body No. 12, the latter solution is seen to be very markedly more pink. Blood from kidneys about 50 per cent. saturated with carbon monoxide. Blood from spleen shows no trace of carbon monoxide bands with spectroscope.

To judge from this experiment there must have been a good deal less than 3·6 per cent. of carbon monoxide in the air which caused death after the Tylorstown explosion.

II. Mouse introduced into air containing 1·8 per cent. of carbon monoxide. Convulsions in 40 seconds. All movements had ceased in 3 minutes.

On post mortem examination, skin pale, liver red and congested, tongue pink. Upper part of small intestine pink. Venous blood from axillary vein 80 per cent. saturated. Solution looks exactly the same tint as that from body No. 12, and gives a very distinct double band after reduction. Spleen, dark red, but did not give enough blood for examination.

III. Another experiment gave the same results as to saturation of the blood, but signs of life continued for longer.

With air containing lower percentages of carbon monoxide down to about ·3 per cent., death is correspondingly less rapid, but the final saturation of the blood is about the same.

In an airway in a mine, after an explosion, the oxygen percentage in the air is much diminished, and this affects the action of the carbon monoxide. Another experiment was therefore made with air diluted 50 per cent. with an indifferent gas representing the nitrogen of the after-damp.

IV. Mouse introduced into air containing 1·8 per cent. of carbon monoxide, and 50 per cent. of hydrogen. Animal fell over in about 20 seconds. Convulsions in about 30 seconds. Cessation of all movements in 2 minutes.

On post mortem examination, skin pale. Lips and tongue reddish-blue. Liver red and congested. Blood from axillary vein and from liver about 80 per cent. saturated. Tint on dilution same as that from body No. 12. Spleen congested. Blood of spleen gives no trace of double bands on reduction with ammonium sulphide, therefore not more than 30 per cent. saturated with carbon monoxide.

Judging by this experiment, there was less than 2 per cent. of carbon monoxide in the air along the track of the explosion, or at least in the air which killed the horses examined, since in the latter the blood of even the spleen was highly saturated with carbon monoxide, and gave a fairly distinct double absorption band after reduction with ammonium sulphide.

Smarting of the eyes and irritation of the air passages seem to be symptoms constantly met with in air containing after-damp. The cause is probably sulphurous acid. After-damp is often referred to in Wales as "sulphur," and its smell is said to be "sulphury." It is difficult, however, to make sure whether these expressions have any reference to the smell of burning sulphur; and when I have myself smelt what I was told was after-damp the smell did not remind me of sulphurous acid, or of any other single gas or vapour. The smell of sulphurous acid would however easily be masked by that of other substances; and as sulphuretted hydrogen is known to be a constituent of coal gas, and to form sulphurous acid on combustion, it seems likely that the symptoms just referred to are actually due to sulphurous acid. The symptoms described by the Ferndale rescuers (p. 7) were such as might be produced by about ·005 per cent. of sulphurous acid at the most, in which case not more than about ·025 per cent. would be present even along the track of the explosion. This percentage is not a poisonous one, and corresponds with the fact that the hæmoglobin was not to any extent decomposed in the bodies examined, and that the respiratory passages of the horses were not inflamed.

It seems probable, to judge from all the available data, that the mixture of gases left along the track of the explosion contained on an average about 1 to 1½ per cent. of carbon monoxide, 50 to 70 per cent. of air, 4 to 6 per cent. of carbonic acid, and the rest chiefly nitrogen. This estimate is of course very rough, but for practical purposes even a rough estimate is of importance, and may serve as a basis for obtaining some idea as to the effect of the after-damp, and the time probably available for carrying fresh air to the men lying along the track of an explosion.

The effects of the deficiency of oxygen and excess of carbonic acid may be referred to first. The presence of 4 to 6 per cent. of carbonic acid would cause slight panting, but nothing more. Along with so much carbonic acid the deficiency of oxygen would have practically no effect, since the panting caused by the carbonic acid would increase the oxygen supply to the lungs, and thus compensate for the deficiency of oxygen in the air.

The percentage of carbon monoxide present would be far more than sufficient to cause death, but the interval before death would certainly be considerable. To judge from the experiments on mice, described above, and from the fact that the respiratory exchange of a mouse is about 20 times as rapid as that of a man (*see* p. 20), the interval would amount to about 40 minutes or an hour. This, then, would be the interval available for rescue. Loss of consciousness would occur much earlier, probably within 8 to 12 minutes, according to an estimate based on the data given on p. 17.

II.—*Heat.*

In the absence of direct experimental data as to the physical and chemical conditions along the track of an explosion, it is only possible to form somewhat rough ideas as to how the burning of the bodies is produced. In the Tylorstown explosion none of the deaths were actually caused by burning, but in many cases, especially when the upper part of the body had not been protected by clothes, it seemed as if a sufficiently large area of skin had been affected to have imperilled life, apart from the effects of after-damp. On this latter point, however, conclusions must be drawn with great caution. At the Park Slip explosion only four out of 110 deaths were, according to the medical evidence given at the inquest, due to after-damp alone, while 100 were due to "burns and shock." Now the Official Report by Messrs. Robson and Atkinson affords the clearest evidence that most of the men killed were nowhere near the flame of the explosion, and that some were actually going about in the workings, and not complaining of burns, for hours after the explosion, before they finally went too far into the after-damp and were killed. It would thus seem that the appearance of the bodies may give rise to quite erroneous opinions as to the severity, or even the existence, of burns.

The heat of combustion of methane (or the gas probably given off from the coal dust) is about 12,000, after deduction of the latent heat of the steam formed. In other words, one unit weight of methane produces in complete combustion heat enough to raise 12,000 unit weight of water 1° C., But for its combustion one volume of methane requires nearly ten volumes of air. Hence the temperature of the exploding mixture does not rise higher than about 2,000° C.[*] Probably this temperature will not be even momentarily reached, since much heat will have been absorbed in heating, liquefying, and distilling the coal dust already suspended in the air.[†]

Just behind the flame there must come a perfect whirlwind of dust, small coal, &c., and this must exercise an enormous and very rapid cooling effect on the hot after-damp. There is commonly about an inch or more of dust on the floor of a haulage road in a mine, and besides this there is much dust on the timbers and rough walls. All of this dust, fine and coarse, will be suddenly swept up by the blast. Assuming that the dust would suffice to form a solid layer an inch thick on the floor, and that a road was 6 feet high, there would be about 1½ per cent. by volume of dust suspended in the hot after-damp. Now the heat absorbed in heating a given volume of coal dust to a given temperature is about 1,000 times the heat absorbed by the same volume of air or after-damp. Hence the addition to the after-damp of 1½ per cent. of coal dust would rapidly cool down the whole mixture to a temperature of about 150° C. A further cooling would, moreover, be brought about by the mixing of the pure after-damp with unburnt air. It was shown above that there is probably 50 per cent. or more of unburnt air in an air-way just after an explosion. The average temperature would therefore, be further reduced to 70° C. or less. Contact of the rushing air with the sides, roof, and floor of the road would cause a further rapid fall of temperature, so that after a very short interval the temperature could hardly be more than 60° C., or 140° Fah. Such a temperature in *dry* air would be by no means formidable, but in the diluted after-damp there would be about 10 per cent. of moisture, so that the hot air at 140° Fah. would be about half saturated, and the dew-point would be at about 115° Fah. In such an atmosphere breathing would be painful, and the body temperature would soon rise. On the other hand, further cooling of the air would soon occur, and the coolest and driest of the air would pass to the floor, so that a man lying there would have the best chance of surviving the effects of the hot air.

It is probable that the excess of dust would not merely act by rapidly taking up the energy of the explosion, but also by condensing and absorbing some of the noxious

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[*] Mallard and Le Chatelier, Annales des Mines, Vol. IV., 1883 p. 509.

[†] The dust from the Albion Colliery, which is close to Tylorstown, yields, according to Mr. Orsman's analysis (published in Mr. Henry Hall's Report to the Recent Commission, p. 15), 14·1 per cent. of volatile matter. If, as seems fairly probable, about half of this volatile matter was given off as coal gas during the explosion, then each volume of dust would give off about one-fourteenth of its weight, or 150 times its volume, of coal gas. Hence, if 0·1 per cent. by volume of fine coal dust were suspended in the air, the gas given off by the dust would produce about the mixture required to yield an undiluted after-damp, such as was actually present at Tylorstown. The presence of very much more than ·1 per cent. of fine dust would seem to imply the absorption by the dust of so much heat, and the production of so much gas, as would stop the propagation of an explosion. On the other hand, with much less than ·1 per cent. not enough gas would be produced to carry on the explosion, or at least to yield an after-damp containing carbon monoxide. We may therefore take about 0·1 per cent. as being on the whole a probable proportion by volume for the dust suspended in the exploding atmosphere. The practical importance of obtaining reliable experimental data on these and other conditions connected with the propagation or non-propagation of dust explosions must be very evident. It seems not unlikely, for instance, that such measures as the removal of excess of dust, and the moderate or partial watering so elaborately carried out in many mines may increase, rather than diminish, the chances of a dust explosion.

volatile or gaseous distillation products. It is well known that coal dust has a marked power of absorbing gases, so that any gas or vapour found in small proportions may easily be taken up by the suspended dust. Even after fresh air has been passing for some time the air of the intake air-ways after an explosion seems to have a slight irritation action on the eyes, as if substances which had been condensed in the dust were being gradually given off again to the fresh air.

The loosening of the epidermis observed in cases of burning (*see* p. 3) is probably caused by the sudden liberation of gas or aqueous vapour between the layers of the epidermis through the temporary action of a blast of exceedingly hot gas. It would seem that this loosening of the epidermis need not imply serious injury. The layer of vapour and gas probably prevents the penetration of heat inwards, except by radiation, just as occurs in the case of any liquid which has assumed the "spheroidal state" by being suddenly brought into contact with a very hot surface. Even the very delicate skin of a frog receives no injury when the animal is plunged for a moment into molten lead.

A colliery official who had been burned in a small explosion in a mine told me that the separation of the outer layer of epidermis on his hands, &c. had been produced at once, and that blistering at certain places had occurred later. The skin from which the epidermis had separated was not cicatrised, but seemed to have a tendency to dryness.

Much doubt must still exist as to the real extent to which life is imperilled by the burns inflicted in dust explosions, but it seems evident that the mere burns are not so dangerous as is generally believed, and that they are seldom if ever of such severity as to be capable of causing the deformities which so frequently follow burns inflicted in other ways.

On reviewing the available evidence and the probabilities, I think that there are at present, at any rate, no sufficient reasons for believing that of the men who have actually died of carbon monoxide poisoning in colliery explosions, any very large proportion have also been burnt in such a manner as would have independently caused death.

III. *Violence.*

Death from mechanical violence alone occurred in the cases of five men, *i.e.*, 9 per cent. of those killed in the Tylorstown explosion. Moreover, of those who died from carbon monoxide poisoning, two or three had (before death ?) received injuries which would certainly have proved fatal. Others were doubtless stunned and rendered unconscious by violence. The injuries produced (fractures of the skull, dislocations, and fractures of the limbs, &c.) are such as might be caused by a considerable volume of air, travelling at a very high rate—not less than 100 miles an hour. The effects produced by the momentum of rushing air are familiar above ground. Thus, in a hurricane, when the difference of lateral, or up and down, pressure between two neighbouring points in the line of direction of the wind, may be so small that no ordinary measuring instrument will indicate it, the force exerted may be such as to blow down walls, trees, &c., and to hurl men and animals against neighbouring objects in the most violent manner. For the production of such effects no very great actual driving pressure behind the advancing blast of air would seem to be required. When a length of sewer or any similar underground passage is connected with the outside air by ventilators at two or more points at some distance from one another, and the wind is blowing in the direction of the sewer, there is a very rapid current of air, so that naked lights may be extinguished at once. Yet in this case the difference of pressure (which drives the air) is too small to be capable of measurement. A driving pressure amounting to a foot of water pressure between two points not far from one another in the air-way of a mine, would give rise to a most violent blast of air, sufficient to cause very formidable effects. Considering that waggons, timbers, cages, &c., along the track of an explosion seem rather to be carried bodily along than simply blown to pieces by the blast of air, it does not seem probable that the actually developed driving pressure (due chiefly to expansion by heating), behind the flash is a large one. Men close to the track of an explosion sometimes notice a sudden rush of air and hissing in their ears. The effect on the ears would be produced by any sudden, but slight, alteration in pressure. The hissing sound would be caused by a little air suddenly passing into or out of the middle ear through the Eustachian tube. Any considerable sudden increase of the pressure of the air would burst the drum of the ear, and cause deafness. Even the relatively gentle and slight increase of pressure which takes place in descending the shaft of a mine may cause unpleasant tension of the tympanum if the Eustachian tubes are blocked by catarrh.

For these reasons I think that the injuries may be set down to the blast of air carrying the men along and bringing their bodies into violent contact with surrounding objects. The practical conclusion to be drawn from this is, that a man who hears the blast approaching should never attempt to run, but should instantly fall flat, if possible in a sheltered position, and out of the way of any waggons which might be blown over him.

THE DISTRIBUTION OF AFTER-DAMP AND OTHER GASES IN A MINE AFTER AN EXPLOSION, OR DURING AN UNDERGROUND FIRE.

In order that the most efficient means practicable be taken for the rescue of men left in a pit after an explosion, it is absolutely essential to understand, not only the composition and properties of after-damp, but also its distribution in the workings. The data contained in a number of special reports on colliery explosions, by Her Majesty's Inspectors of Mines, fortunately furnish the material required for this part of the investigation.

Thanks to the work of Mr. William Galloway and others, I think it may now be taken as proved beyond all doubt, that in great colliery explosions the flame, whatever may have been its original starting point, is propagated along the roads of the mine by coal dust, and, in nearly every case, by coal dust alone. Not only has it been proved experimentally that coal-dust, without admixture of fire-damp, will propagate an explosion, but the evidence obtained from the state of the roads, &c., after an explosion, shows that the flames travels along the dusty haulage roads (where there is usually no trace of fire-damp), and those only.* Whatever be the conditions necessary for the propagation of a dust explosion, these conditions are as a rule fulfilled along a dry or moderately dry haulage road, provided the dust is sufficiently sensitive. The after-damp left after an explosion is therefore formed, as a general rule, along the haulage roads. In the great majority of cases these haulage roads are the main intake airways, besides being the paths used for access to the workings, and it is along them that men in the workings during an explosion naturally endeavour to escape. This latter fact, as I believe, contributes very largely to the loss of life after explosions.

When an explosion passes in the usual way along the main intake roads of a mine, doors, stoppings, and air-crossings are destroyed. In consequence of this the ventilation is short-circuited, so that the air from the down-cast shaft, instead of passing inward towards the workings, passes more or less directly to the up-cast shaft. The intake roads further in thus remain charged with after-damp until the injured doors, &c., have been temporarily repaired by rescuers, who gradually work their way in, carrying the air with them along the intake roads as each short-circuiting opening towards the return air-way is repaired. Any slight ventilation which may have existed before the rescuers have passed in will usually tend to carry the after-damp directly into the returns through the blown-out doors. Moreover, much after-damp will usually have been forced directly into the returns during the explosion itself, so that men who may be alive in the workings beyond the limits of the explosion, will at first be effectually shut off by the presence of after-damp in both the intake and return airways.

Meanwhile, with the cessation of ventilation, fire-damp will have begun to accumulate at the face, so that the imprisoned men will have fire-damp behind, as well as after-damp in front of them. The fire-damp, however, will have the good effect of tending to drive the far more dangerous after-damp back towards the shaft, and thus open a way in front. The effect of accumulating fire-damp in clearing out after-damp may be very considerable. In the upcast shaft of the Tylorstown Colliery, there was 1·87 per cent. of fire-damp, with an air current of 260,000 cubic feet per minute. The accumulating fire-damp over the whole pit would thus be capable of displacing 5,000 cubic feet of after-damp per minute.

After a sufficient time, the after-damp in the intake air-ways will have either been driven out, or at least become very much diluted by admixture with the air of the

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* *See* in particular the monograph on Colliery Explosions, by Messrs. W. N. and J. B. Atkinson, Her Majesty's Inspectors of Mines. Longmans, 1886.

numerous communicating spaces filled with fresh air. This mixing will be favoured by the difference in specific gravity between the after-damp and the air (*see* p. 13). When a certain stage of dilution (probably about a tenth to a twentieth of the undiluted after-damp) has been reached, it will be just possible for a man to get from the workings to the shaft without being overcome. In cases where the flame has passed inwards to the face or close to it, there may not be sufficient air available beyond the roads affected to dilute the after-damp to a non-poisonous percentage. In many cases, however, there will be, beyond the limits of the explosion, abundance of air to effect the dilution, so that a man who waits for the rescuers, or long enough for the after-damp to disperse, will be able to escape, either by the intake, or, if this is blocked by falls, by the return air-ways, which, not having been traversed by the explosion, are nearly always free from falls.

In the Tylorstown No. 8 pit, the flame had evidently reached the working face at various points, and all the men in the pit were dead when found. Yet mice were seen running about uninjured at several points in this pit when the explorers got in. There must therefore have been places where the after-damp, if present at all, was so dilute as to be non-poisonous.

When men are prevented from escaping from a district by after-damp or falls, the air enclosed with them may last for days, but will gradually be replaced by fire-damp and black-damp. If the mine is a fiery one, the best air will probably be at the lowest places, since the fire-damp, with admixed black-damp, will rise. If the mine is not a fiery one, only black-damp will be formed, and the freshest air will be at the highest places. Any carbon monoxide present will, unfortunately, tend to become more and more poisonous* the more the air becomes vitiated by either fire-damp or black-damp. On the other hand the coal dust, and coal lying along the roads, at the face, &c., will probably absorb some of the carbon monoxide.

Distribution of Smoke in Underground Fires.

Some of the most disastrous colliery accidents in recent years† have been due, not to explosions, but to fires. In these cases the smoke and gases from a fire in or about the downcast shaft or main intake airways, have been carried all over the workings by the ventilation current, killing every man on their path. The chief cause of death is probably carbon monoxide poisoning, although there is no direct medical evidence that this is the case.‡ Apart from the existence of some such poisonous gas in the smoke, it does not seem possible to account for the terrible effect produced on the men. The gases would be too much diluted for their effects to be attributable to absence of oxygen; and there would not in any case be sufficient carbonic acid present to cause death. The more perfect the ventilation of the pit the more certainly will the fan carry the deadly gas into every airway and working place.

The Positions at which the Bodies are found after an Explosion.

By a careful study of the distribution of the bodies found after an explosion, and of the men found alive, much may be learned as to the causes of death and the chances which the men would have had of escaping had they possessed the requisite knowledge and coolness.

On studying the plans and descriptions showing the condition of things after a great explosion, it is in the first place evident that the bodies are, as a general rule, found along, or close to, the track of the explosion. When the explosion has not reached the workings, bodies are not found there, but only on the haulage roads, or,

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* *See* Journal of Physiology, Vol. XVIII., p. 201.

† For instance, at the Mauricewood Colliery, 1889 (63 lives lost), at the Great Western Colliery, 1893 (63 lives lost), and at Thornhill Colliery, 1893 (139 lives lost).

‡ From personal inquiries of an official who led a rescue party during an underground fire, I satisfied myself that the symptoms felt by him (in an atmosphere in which lamps still burned) corresponded to those of carbon monoxide poisoning. On the other hand, symptoms which seem to point to irritant poisoning have also been described as caused by smoke.

PLAN Nº 1.
SEAHAM COLLIERY.

Scale 8 Chains per Inch.

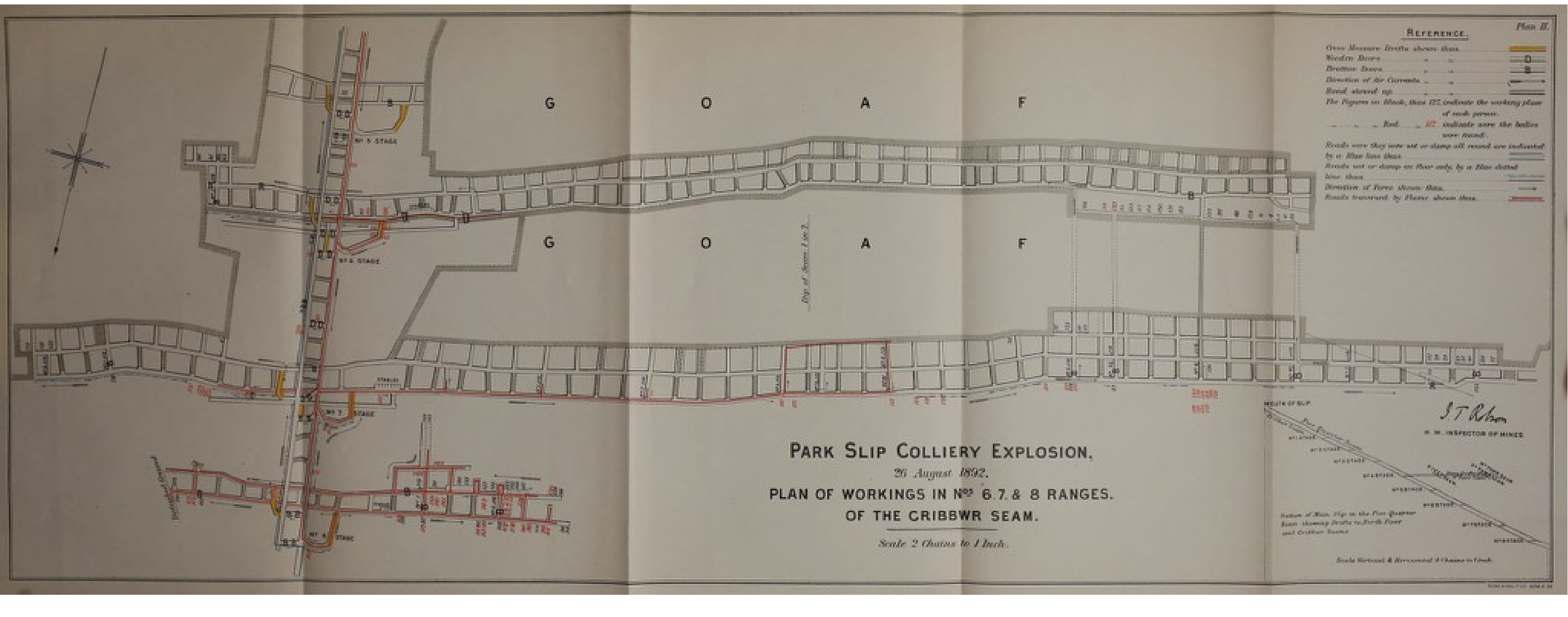
8TH SEPT 1880.

Roads traversed by the Explosion shewn by a dotted line

REFERENCE.

Intake Air ways coloured blue
Return " " " pink
Working faces thick black lines
Old Workings thin " "
Goaf shaded
Doors D
Regulators R
Air Crossings, built
" " natural
Stoppings
Caution boards or lamp stations C
Engine landings
Places where bodies of men were found. A figure shews the Nº in a group

[‡] From personal inquiries of an official who led a rescue party during an underground fire, I satisfied myself that the symptoms felt by him (in an atmosphere in which lamps still burned) corresponded to those of carbon monoxide poisoning. On the other hand, symptoms which seem to point to irritant poisoning have also been described as caused by smoke.



Park Slip Colliery Explosion,

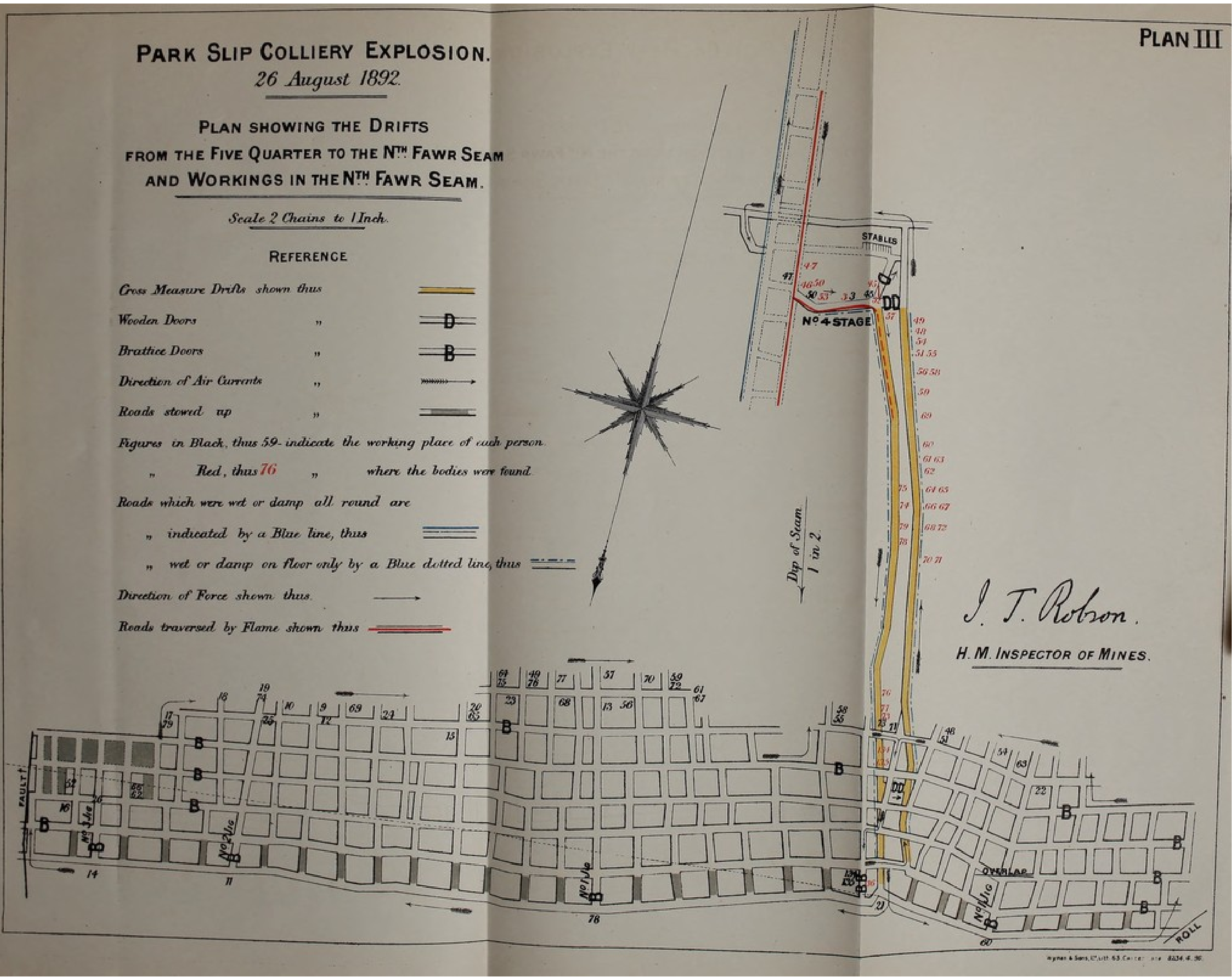
26 August 1892.

PLAN OF WORKINGS IN Nos 6.7.& 8 RANGES. OF THE CRIBBWR SEAM.

Scale 2 Chains to 1 Inch.

J. T. Robson
H. M. INSPECTOR OF MINES

PLAN III



PARK SLIP COLLIERY EXPLOSION.

26 August 1892.

PLAN SHOWING THE DRIFTS FROM THE FIVE QUARTER TO THE NTH FAWR SEAM AND WORKINGS IN THE NTH FAWR SEAM.

Scale 2 Chains to 1 Inch.

REFERENCE

Cross Measure Drifts shown thus	🟨
Wooden Doors „	D
Brattice Doors „	B
Direction of Air Currents „	→
Roads stowed up „	▬

Figures in Black, thus 59 - indicate the working place of each person.

„ *Red, thus 76* „ *where the bodies were found.*

Roads which were wet or damp all round are

„ *indicated by a Blue line, thus* ═

„ *wet or damp on floor only by a Blue dotted line, thus* ┅

Direction of Force shown thus. ⟶

Roads traversed by Flame shown thus 🟥

J. T. Robson.

H. M. INSPECTOR OF MINES.

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in some cases, in return air-ways adjoining the track of the explosion.[*] If an explosion does penetrate from the haulage roads into the workings, or if it has originated in the latter, some of the bodies are found in the workings and others on the haulage roads which lead to the workings. Wherever after-damp has been formed by the explosion, or has been afterwards carried, there the bodies are found.

Another fact is also very evident, namely, that a large proportion of the bodies are found close together on the haulage roads, just about where the after-damp would be met by the men making their way out towards the shaft. It is only too obvious that these men have from want of knowledge gone straight to their deaths in endeavouring to escape. As soon as they had been long enough in the dilute after-damp to absorb a certain volume of carbon monoxide they had simply fallen powerless, so that they could not return, and they must soon have lost all consciousness. This matter is of so much practical importance that I have reproduced in illustration of it plans showing the effects of the Seaham and Park Slip explosions. The first plan is taken with slight modifications from the Messrs. Atkinson's book on "Explosions in Coal Mines," and the second and third from the Report of Messrs. Robson and Atkinson on the Park Slip explosion. These plans serve at the same time to illustrate the course taken by colliery explosions, and to enforce the lesson so often repeated as to dust being the means of propagation.

The plans show not only the positions of the bodies, but also the extent of the explosions. It will be noticed that in the Seaham explosion nearly all the bodies were found in groups at just about the points where the men who had been working at the face would meet the after-damp while on their way to the shaft. At the Park Slip explosion the flame at one or two places (No. 8 Range) reached right up to the face, so that the men had not been able to go any considerable distance before they fell. At other places the flame only reached the entrance of the main roads leading towards the face, so that some of the men had gone a quarter of a mile or more before reaching the after-damp. Many of the men in the No. 7 Range and North Fawr workings escaped by remaining for about 24 hours near the face, but unfortunately the majority walked into the after-damp and perished.

It is exceedingly difficult to estimate how many of the men who have been lost in recent explosions might have been saved had they taken the means available of avoiding the after-damp, or, indeed, had they simply stayed in their working places. In some cases, for instance, in the Pantddu district (in which there were 37 men) after the Albion explosion, or in the North Fawr workings (in which there were 56 men) after Park Slip explosion (Plan No. 3) it seems clear that all the men in the district might have been saved had they waited till the after-damp in the roads had dispersed.

The following table summarises the situation in which bodies were found after a number of recent explosions :—

Mine.	On or about Haulage (nearly always Intake) Roads.	At the Working Face.	In Return Air-ways.	Total.
Seaham, 1880 - - -	116	1	44	161
Trimdon Grange, 1882 - -	37	27	3	67
Tudhoe, 1882 - - -	31	4	2	37
Usworth, 1885 - - -	30	2	10	42
Udston, 1887 - - -	31	36	—	67
Brynmally, 1889 - - -	15	5	—	20
Hyde, 1889 - - -	17	6	—	23
Llanerch, 1890 - - -	136	27	11	174
Morfa, 1890 - - -	42	—	1	43
Mossfields, 1890 - - -	36	—	—	36
Park Slip, 1892 - - -	58	6	26	90
Albion, 1895 - - -	194	76	6	270
Tylorstown, 1896 - - -	42	15	—	57
	785	205	103	1,088

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[*] The well-known colliery "Viewer," John Buddle, in a paper written in 1813, estimated the proportion of deaths by suffocation after an explosion as at least 75 per cent. of the whole deaths. From an analysis of the plans published in one or two recent explosions, I arrived at a very similar estimate (British Association Report, 1894). The causes of death assigned at the inquests seemed to be mostly incorrect. From the facts ascertained at the Tylorstown explosion, it would seem that 90 per cent. of the deaths in colliery explosions are in reality due to after-damp.

From this table it will be seen that more than 80 per cent. of the bodies are found on the haulage roads or adjoining air-ways. Of these men a certain proportion were actually employed, at the moment of the explosion, on roads traversed by the flame. When all due allowance is made for this fact, however, it is still quite clear that most of those killed met their death from after-damp while endeavouring to reach the downcast shaft by the haulage roads in the ordinary way. Not only are these men stopped through being overpowered by carbon monoxide, they are also stopped by the falls, which occur along the track of the explosion in consequence of the displacement of timbering. Even though a road may not be altogether blocked by falls, it is usually almost impassable for a man without a light. The chances of hurrying out through the after-damp are thus exceedingly small. Apart from after-damp there is, moreover, great danger at first from the fact that new portions of the roof are constantly coming down, and the least touch may bring down more.

After underground fires the bodies are also found, as a rule, along the intake roads, where the men have dropped while hurrying out towards the downcast shaft. In their anxiety to escape they have run straight into the poisonous air. This is clearly shown in the plans accompanying the official reports by Mr. Robson on the Great Western Colliery fire, and by Messrs. Wardell and Hall on the fire at Thornhill Colliery.

SUGGESTIONS as to the SAVING of LIFE after COLLIERY EXPLOSIONS and FIRES.

It seems probable from the facts detailed above that much can be done towards limiting the loss of life in colliery explosions, and a few suggestions on this subject may, I hope, be of practical service.

Nearly everything that can be recommended must depend for its success on previous preparation and organisation. The first matter to attend to, on the part of those above ground, is to get fresh air into the pit as rapidly as possible. The facts brought to light by the present investigations show clearly that a very small proportion of those who perish in an explosion are killed instantaneously. According to the calculation on page 24 an interval of as much as an hour probably elapses in most cases before even the men lying along the track of the explosion are dead. It is thus evident that anything, which can be done within this interval towards clearing away the after-damp may be the means of saving many lives.

As a rule, the fan itself escapes injury in an explosion, but the timbering of the passage connecting the fan-drift with the fan is blown out, so that the air passes directly to the fan from the outside, instead of from the upcast shaft. Sometimes also the covering of the upcast shaft is displaced or injured. It is usually possible to repair the damage within an hour or two, but meanwhile little or no air is entering the pit, and many of the men must already have succumbed to the carbon monoxide. This delay would apparently be obviated by the provision between the fan-drift and the fan of a sufficient number of light movable flaps opening outwards, and so made as to close automatically as soon as the pressure from the explosion had relieved itself. The cover to the top of the upcast shaft should also be so arranged as not to be easily injured, or, failing this, there should be some supplementary arrangement for quickly closing the top of the shaft in the event of an explosion occurring.

As doors, air-crossings, and stoppings will have been destroyed along the track of the explosion, the air which passes down the downcast shaft usually goes, at first, almost directly into main return air-ways, and so into the upcast shaft. To obviate this it seems desirable that, as far as possible, the communications between intakes and returns in the immediate neighbourhood of the shafts should be narrow, and provided with doors of sufficient strength to resist the pressure of an explosion; also that air-crossings in this neighbourhood should be in the solid, and that all stoppings should be solidly stowed. Were these precautions successful, it would be possible to clear without delay the main roads all round the shafts. Let us suppose that the downcast shaft was 1,500 feet deep, and 16 feet in diameter, and that the fan gave a ventilation of 150,000 cubic feet per minute. The capacity of the shaft would be about 300,000 cubic feet. The fan would therefore be capable of clearing it within two minutes. A similar calculation will show that the after-damp in a mile of the main roadways round the shaft might be displaced within other two minutes. The men within the area cleared would thus be placed out of danger of suffocation, as even allowing for a delay of ten minutes before the air current could be re-established, fresh air would reach them before they could have absorbed sufficient carbon monoxide to cause death. A way of escape would also probably be opened at once for men in districts not affected by the explosion, and all immediate danger to rescuers descending at once into the pit would be obviated. A further advantage of getting air speedily into the main roads would be that this air would not be impeded by falls to such a serious extent as is the case at a later stage. The falls after an explosion seem to come down for the most part gradually from the displacement of timbering, and not from the direct action of the explosive force. As long as the after-damp continued warm, the fresh air, being heavier, would probably also run along the floor for considerable distances beyond the first blown-out door and air-crossings, and a corresponding volume of after-damp would pass out along the roof. For all these reasons it seems of great importance that the attention of mining engineers should be directed to devising arrangements by which fresh air could be got down the shafts, and as far as possible along the main roads, with the least avoidable delay after an explosion.

Where there is more than one down-cast shaft, as at Tylorstown, the effect of the explosion will be to throw one of the shafts entirely out of action. To meet this contingency it would be necessary to arrange for partially blocking off the air current down the downcast shaft nearest to the upcast.

The next point to consider is the best means of getting rescue parties down a pit as soon as possible. Very frequently the shaft and cages are damaged, and this causes much delay. To obviate damage to the shaft, it seems of great importance that the main roads for at least 100 yards on each side of the shaft should be so arranged that the floor could always be kept thoroughly wet, and that the sides and roof should either be smooth, and *entirely* free from coal dust, or else kept thoroughly wet like the floor. Were this done, not only would the shaft be protected, but an explosion coming from one side of the pit would, judging from past experience, be stopped at the shaft. The shaft itself should also be kept wet if it is not so naturally. Corresponding precautions are equally desirable in mines worked by means of a main incline.

The steps to be taken as regards the organisation and direction of rescue parties should be arranged beforehand by the Manager, and made known to all the officers of the mine, so that no unnecessary delay should occur. The dangers to rescuers who trust to warning given by their lamps, when going into air containing after-damp, should also be clearly explained, as well as the danger from falls of the roof where timbering has been blown out. As shown above (p. 20) the presence of a dangerous proportion of after-damp or other suffocative gas may be detected easily and sufficiently quickly by observing the symptoms of a mouse, or other equally small warm-blooded animal. A few white mice might easily be kept for this purpose in the engine room at the top of the downcast shaft, and be taken down in small cages by the rescuers. With the help of the indications afforded by the mice it would be possible for the rescuers to keep within the limits of safety, and yet to go forward with rapidity and confidence as far as they could.

The main point for the rescuers is, evidently, to push forward with the necessary apparatus, and restore the broken doors &c., with a view to getting fresh air to the bulk of the imprisoned or disabled men, who will mostly be near the face. It is not only dangerous, but in most cases practically useless for the rescuers to go into the workings unless they take fresh air with them. The care of the injured should be left to men instructed in ambulance work. When it is impracticable or unsafe to climb at once over a fall an air-current may nevertheless in many cases be directed through it, and may suffice to clear the return air-way up to the next blown out door, and thus enable rescuers to get round into the intake again. The danger of going into a return air-way without any means of detecting a poisonous proportion of after-damp must be evident.

After a time the air-ways near the face will become charged with fire-damp and black-damp, and the presence of these gases will cause additional difficulties, which will increase the delay in getting in. About 5 per cent. of fire-damp, or 15 per cent of black-damp, will extinguish a lamp (see p. 21), but about 50 per cent. of either of these gases would be required to cause any formidable symptoms in a man. Hence a man may safely go for rescue purposes into air containing either of these gases for a considerable distance beyond the point where an ordinary lamp is extinguished. With the precautions referred to at p. 16, electric lamps may be used for penetrating such atmospheres. Any immediate danger would be indicated by the symptoms of a mouse carried by the rescuers. It is probably often the case, after an explosion, that men near the face have lain for long unconscious, but still alive, in air containing much fire-damp or black-damp.

Where it is desirable to go temporarily into air which is quite irrespirable from the presence of after-damp, fire-damp, or black-damp, an oxygen apparatus, of the kind referred to below, would be of service. Apparatus of this description should, I think, be at hand, but need only be used in special cases.

The saving of life after an explosion depends, not merely on the action of rescuers, but still more on that of the men in the pit themselves. At the least warning of approaching flame or disturbance a man should at once fall flat. In this way both burning and violence may be partly or completely avoided. Moreover the air along the floor will be cooler and contain less after-damp, and when fresh air comes it will come first along the floor. Any exertion will (by causing the respirations to become quicker and deeper) hasten the action of the after-damp.

For a man near the shaft, the best plan would probably be to lie still. For a man in a road, far in, the most hopeful way of escape, if consciousness remained, would be towards a return air-way, or towards the face.

Those at the face, or on roads not traversed by the explosion, should on no account hurry towards the shaft by the haulage roads. To do so will entail almost certain death if the explosion has traversed any part of the road towards the shaft, and even, if this has not been the case, after-damp may have been blown by the force of the explosion into some part of this road. Any attempts to reach the shaft should, therefore, be made with the utmost caution, and when after-damp is met the only safe course is to retire again into fresh air. The after-damp can be detected by its smell and its irritating effect upon the eyes, and any mistiness or unusual warmth in the air should be regarded as a sign of its presence. It should be remembered that the more time can be gained by retiring before the after-damp, the greater chance there will be of its clearing away, or becoming so dilute as to be harmless. There is no doubt that hundreds of men have lost their lives by hurrying blindly towards the shaft, or by not retiring towards the face when they met the after-damp.

What may be done by coolness and resource was strikingly shown in the case of Roderick Williams, a fireman, who was alone in one of the districts of the Tylorstown Colliery at the time of the explosion. Finding the ordinary road to the No. 7 shaft blocked by after-damp, he retired before it, and went round by the return air-way. Again meeting after-damp before reaching the shaft, he retired into some old workings and waited for an hour or two, after which he found that the after-damp had cleared sufficiently to enable him to pass through the doors into the main road, where he met the rescuers on their way in and helped them to explore the rest of the pit. He had previously escaped in a similar manner from two disastrous explosions, at one of which he saved the lives of a large number of men by forcibly preventing them from getting past him towards the shaft. One man whom he could not stop was afterwards found dead nearer the shaft.

When the after-damp not merely cuts off the way of escape, but threatens to pass inwards towards the face, much may be done by erecting curtains or stoppings, and retiring behind them, also by opening doors into the returns, so that when the ventilation is restored by rescuers the after-damp may not be carried further inwards.* The men who escaped after 30 hours imprisonment from the workings in the No. 7 range at Park Slip explosion (Plan No. 2) had erected a stopping to keep back the after-damp.

After a few hours escape will generally be possible either by the main road or by the return air-way. The latter path will have the advantage of being clear of falls. If the blast of air, or the accumulation of fire-damp at the face has extinguished the lamps of those shut up in the workings, their chance of escape will be very much diminished. For this reason I should suggest that electric lamps be kept at certain places near the face in each district, for use in any emergency. For the detection of after-damp, or dangerous proportions of fire-damp, a few mice might be kept in cages near them. The light of an electric lamp, and the indications afforded by a mouse, would enable a party to take the best means of escape, and to avoid the dangers which have caused the deaths of so many men.

There can be no doubt that an explosion frequently comes too near the face for the men working there to escape by the means just recommended, although a considerable interval may elapse before the after-damp closes in, or causes loss of consciousness. In such cases escape would still be quite possible were the men provided at their working places with apparatus for maintaining life in irrespirable atmospheres, and were electric lamps available for lighting parties of men on their way out.

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* A number of valuable suggestions in this direction are contained in paper contributed by Mr. Simon Tate the "Transactions of the Federated Institution of Mining Engineers," Vol. VIII, 1894, p. 189.

It would require about 120 litres, or 4 cubic feet, of oxygen to keep a man alive for two hours while making his escape to the shaft, or for six hours while remaining at rest. At the commonly employed pressure of 120 atmospheres, this volume of oxygen can be compressed into a steel cylinder of the capacity of 1 litre, or 1¾ pints. The apparatus required for economically breathing this oxygen must be constructed on the principle known to physiologists as that of Regnault and Reiset's Respiration Apparatus. In a paper on Colliery Explosions, read before the British Association meeting in 1894, I described two simple models of apparatus of this kind; and many years ago Mr. Fleuss devised a more elaborate one on the same general lines. But for the fortunate circumstances that colliery explosions are of such rare occurrence appliances of this kind would doubtless have already come into use. Compressed air would not be nearly so available as pure oxygen, since at least ten times as much of it would be required. No respirator would be of any use against after-damp, as there is no known absorbent which could be practically applied to arrest carbon monoxide.

It has been proposed to construct air-tight refuge chambers, with narrow and strong double doors. At the face they might be of great service. 100 cubic feet of air would suffice to keep a man alive for ten hours. A chamber 20 feet square by 6 feet high might thus preserve the lives of 24 men for ten hours. It would, however probably be difficult in practice to make such refuge chambers even approximately air-tight, and the trouble and expense would be considerable.

In the case of a fire occurring in or near a main air-way in a mine, any hesitation or mistake on the part of the officers of the pit may have terrible consequences. It is therefore of great importance that the danger be thoroughly realised, and such orders issued beforehand by the Manager that the promptest action may be taken by those on the spot.

The main points are to keep the smoke and gases from the fire from entering the workings until the men are withdrawn, and to prevent men from running into the smoke in their efforts to get out. The ventilation to the seat of the fire should, therefore, be cut off as soon as possible, so that smoke may not be carried inwards. If the fire is in or near the downcast shaft, the fan should be stopped at once, and the top of the upcast shaft opened, so that the smoke may pass up the downcast. Meanwhile the men in the pit should be withdrawn past the seat of the fire by the return air-way, a man being also stationed, if possible, at some point on the intake beyond the fire to prevent others from running into the smoke.*

Should the smoke get far into the workings, the men cut off by it ought not to attempt to reach the shaft through the smoke by the intake. In many cases they will be able to reach the upcast shaft in time by hurrying out along return air-ways if they know the way. Failing this their wisest course will be to go at the first warning as far as seems safe along the intakes, and there to open a door into the return air-way, so as to short circuit the smoke. They should then erect curtains to keep the smoke back, and direct it all into the return air-ways.† In this manner time will be gained; and, even if the fire cannot be got under, those on the surface may be able to stop, or partly reverse, the ventilation, and thus render escape by the return air-ways possible.

I am, Sir,
Your obedient servant,
JOHN HALDANE.

The Right Hon. the Secretary of State
for the Home Department.

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* As an example of what can be done in this way I would instance the case of the underground fire at Bamfurlong Colliery in 1892, where, by the prompt action of Mr. Foster, the Under-manager, what might otherwise have been a much more serious disaster was avoided.

† By taking this course, Thomas Rosser, fireman, succeeded in saving the lives of the 78 men in his district at the Great Western Colliery fire. Before the party could be rescued the accumulating fire-damp was closing in on them from behind. In another district of the same pit the fireman, David Davies, had collected and sent out by the return as many men as possible. He himself lost his life while trying to help a collier who was lame.

APPENDIX A.

POST MORTEM APPEARANCES and CAUSES OF DEATH of those KILLED at TYLORSTOWN EXPLOSION.

Number.	Description.	Cause of Death.
1	Engine-driver. Body and hands burnt. Hair and whiskers singed	Carbon monoxide poisoning ?
2	Ostler. Back of head and right side of face covered with coal dust and singed. Lips and nails bluish (not pink). Extensive scalp wound behind, and probable fracture of skull. Spinal column dislocated in dorsal region. Fracture of left humerus, and dislocation of right shoulder. [Found in stable, beside a number of living horses and a companion who escaped. Injuries probably due to violent contact with the timbering of the stalls, and to the kicking of the horses.]	Violence.
3	Collier.† Body pale. Lips, tongue, and nails pink. No burns or injuries	Carbon monoxide poisoning.
4	Ostler. No injuries or burns. Skin pale. Lips, tongue, and nails pink	Carbon monoxide poisoning.
5‡	Collier. No burns or injuries. Nails pink. Lips, &c. pale pink	Carbon monoxide poisoning.
6	Collier. No burns or injuries. Skin pale. Lips, tongue, and nails pale pink	Carbon monoxide poisoning.
7	Collier. No burns or injuries. Skin pale. Lips pale pink, tongue and nails pink.	Carbon monoxide poisoning.
8	Collier. No burns or injuries. Some patches of pink on chest. Lips carmine-red. Nails pink.	Carbon monoxide poisoning.
9	Labourer. No burns or injuries. Pink flush on chest and neck. Lips pink	Carbon monoxide poisoning.
10	Collier. No burns or injuries. Skin pale. Lips, tongue, and nails pale pink	Carbon monoxide poisoning.
11	Labourer. No burns or injuries. Tongue and lips pink	Carbon monoxide poisoning.
12	Collier. No burns or injuries. Skin pale. Lips and tongue pink. Hæmoglobin of blood from left external jugular vein found to be 79 per cent. saturated with carbon monoxide.	Carbon monoxide poisoning.
13	Collier. No burns or injuries. Skin pale. Lips, tongue, and nails pink	Carbon monoxide poisoning.
14	Labourer. No burns or injuries. Tongue, lips, and nails, pink	Carbon monoxide poisoning.
15	Collier. Body covered with a layer of adherent coal dust, and scorched superficially. Lower jaw fractured. Lips bright red.	Carbon monoxide poisoning.
16	Collier. Body covered with adherent coal dust and superficially scorched. Tongue and lips coated with coal dust. Lips red beneath the dust.	Carbon monoxide poisoning.
17	Fireman. Marks of superficial burns on face, forearms, and hands. Superficial layer of epidermis on hand loosened. Under loosened epidermis carmine red colour seen very distinctly.	Carbon monoxide poisoning.
18	Ostler. Hair singed. Scalp wound. Lips and nails pink	Carbon monoxide poisoning.
19	Haulier. No burns or injuries. Face and neck much congested. Lips reddish-blue. Tongue protruded and bluish. A network of distended reddish-blue veins prominent on upper part of chest. [No. 21, who was found in the same stable, also presented these appearances, which might be caused either by poisoning with a higher percentage of carbon monoxide than was usually present, or by asphyxia from deficiency of oxygen along with carbon monoxide poisoning.]	Carbon monoxide poisoning and deficiency of oxygen.
20	Labourer. Fracture of humerus in both arms. Dislocation of right hip-joint. Bleeding from ear, and probable fracture of base of skull. Hair and eyebrows singed. Nails, &c. blue (not pink).	Violence.
21	Ostler. No burns or injuries. Marked cyanosis of face and chest. Face dusky red. Nails bluish pink. Network of distended reddish-blue veins on upper part of chest.	Carbon monoxide poisoning and want of oxygen.
22	Ostler. Face and hands somewhat scorched. No injury. Face pink all over	Carbon monoxide poisoning.
23	Collier. Slight singeing of side of face, hair, and whiskers. Lips pale pink	Carbon monoxide poisoning.

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* The numbers correspond with those marked on the plan produced at the inquest (*see* Mr. Robson's special report). The names are purposely not added. With the exception of Nos. 1, 4, 6, 7, 10, 11, 14, 26, 36, 37, 47, 48, which had previously been examined by Dr. Morris alone, the bodies were examined by both Dr. Morris and myself. In two or three cases where the colour of the blood was not noted the most probable cause of death has been assigned.

† Nos. 3, 11, 12, 13, and 14 were found lying dead together, with two lamps burning beside them.

‡ Nos. 5, 6, 7, 8, 9, and 10 were found dead together, with a lamp burning beside them.

Number.	Description.	Cause of Death.
24	Collier. No injuries or burns. Face red. Nails pink - - -	Carbon monoxide poisoning.
25	Labourer. Brain and abdominal cavity exposed. Both legs and arms smashed. Body scorched, and clothes torn off.	Violence.
26	Master Haulier. Face and hands scorched superficially. Face very pink. Pink colour also very marked under loosened epidermis of front of fingers.	Carbon monoxide poisoning.
27	Fireman. Hair singed. Superficial burn of face, which is brick-red. Epidermis loosened over hands, and bright red colour visible under epidermis of front of fingers.	Carbon monoxide poisoning.
28	Collier. Superficial burns of face, hands, chest, and back. Pink inside lips, and where epidermis peeled off on front of fingers.	Carbon monoxide poisoning.
29	Haulier. Skin superficially scorched on exposed parts. Red colour visible beneath denuded epidermis. No injuries.	Carbon monoxide poisoning.
30	Collier. Hands and face superficially scorched. Hair and whiskers singed. Ecchymosis of blue colour of lower lip. Lips otherwise red. Bleeding from ear, and probable fracture of base of skull.	Carbon monoxide poisoning.
31	Collier. Hair singed. Epidermis of hands loosened. Lips pink. Red flush on chest. Under epidermis on front of hands carmine-red colour.	Carbon monoxide poisoning.
32	Collier. Superficial burns of face, forearms, and hands. Hair and eyebrows singed. Carmine-red on lips and under epidermis on front of fingers.	Carbon monoxide poisoning.
33*	Labourer. Face pink. Lips pale. Teeth closed on tongue. Nails pink. No burns or injuries.	Carbon monoxide poisoning.
34	Labourer. No burns or injuries. Skin pale. Lips and nails pale pink -	Carbon monoxide poisoning.
35	Collier. No burns or injuries. Pink flush on skin. Face lifelike. Lips pink.	Carbon monoxide poisoning.
36	Haulier. Superficially scorched all over above legs. No injuries - -	Carbon monoxide poisoning?
37	Fitter. Body superficially scorched above legs - - - -	Carbon monoxide poisoning?
38	Haulier. Skin pale. Hardly any pink tinge visible anywhere. Blood seems only partially saturated with carbon monoxide, and had probably been partially freed by the action of fresh air before death. (*See* Note No. 33.)	Carbon monoxide poisoning.
39	Master haulier. Face covered with caked coal dust. Epidermis peeled off in parts. Parts of skin have colour of red sealing-wax. Lips bright red. Teeth closed on tongue.	Carbon monoxide poisoning.
40	Haulier. Superficial scorching of hands and face. Hair singed. Face vermillion-red. Lips pink.	Carbon monoxide poisoning.
41	Labourer. Hands, face, body, and legs superficially scorched. Hair singed. Face carmine-red colour.	Carbon monoxide poisoning.
42	Labourer. Scorched a good deal on right side of chest, face, and hands. Hair and eyebrows singed. No pink or red colour visible. No carbon monoxide found in sample of blood taken from external jugular vein. May probably have died in fresh air, after blood had been freed of carbon monoxide.	Carbon monoxide poisoning?
43	Collier. Face and body covered with caked dust. Unrecognisable. Found with no clothes, and only one shoe on. Dislocation of left shoulder. Lips bright pink beneath the coal dust.	Carbon monoxide poisoning.
44	Haulier. Scorched all over superficially. Inside of mouth coated with coal dust. Hair and moustache singed. Red coloured vein visible on shoulder where protected from burning. Face carmine-red. Lips and tongue very pink beneath the dust. Nails pink. Hæmoglobin of blood from external jugular vein found to be 79 per cent. saturated. No injuries.	Carbon monoxide poisoning.
45	Labourer. Scorched all over body and hands. Hair singed. Under loosened epidermis of front of fingers carmine red colour.	Carbon monoxide poisoning.
46	Collier. Superficially scorched over exposed parts. Hair singed. Epidermis of hands loosened, and on stripping it off carmine-red colour visible on front of fingers. Face very red. Lips pink.	Carbon monoxide poisoning.
47	Rider. Upper part of skull and brain nearly all removed. Face and hands burned. Both arms fractured.	Violence.
48	Ostler. Slight general scorching of exposed skin and hair. Pink patches on body. Lips and tongue pink.	Carbon monoxide poisoning.
49	Haulier. Hair singed, and face superficially scorched, and bright sealing-wax red colour in patches. Coal dust had been washed off. No injury.	Carbon monoxide poisoning.
50	Haulier. Skull fractured. Generally scorched on exposed parts. Hair singed. Lips red.	Carbon monoxide poisoning.
51	Collier. Exposed parts of skin scorched. Hair and eyebrows singed. Inside of lips pink, also under epidermis of front of hands.	Carbon monoxide poisoning.
52	Collier. Face, hands, and arms, badly scorched on surface. Epidermis covered with coal dust. Carmine-red colour visible on front of fingers on peeling off epidermis.	Carbon monoxide poisoning.
53	Fireman. Superficially scorched over exposed parts. Pink inside lips, and under loosened epidermis on front of fingers.	Carbon monoxide poisoning.
54	Collier. Skull fractured. Body scorched on exposed parts. Inside of mouth coated with coal dust. Wound of finger. Lips red beneath the dust.	Carbon monoxide poisoning.

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* Nos. 33, 34, 35, and 38 were found lying together about 10 hours after the explosion, along with a man who was still alive, and who recovered under treatment.

Number.	Description.	Cause of Death.
55	Fireman. Covered with caked dust, and generally scorched. Inside of mouth bright red beneath the dust.	Carbon mnooxide poisoning.
56	Fireman. Body much mutilated. Neck severed. Chest covered with caked coal dust. Right leg fractured and twisted. Left leg torn off below the knee. Right shoulder torn away, also half of left arm. No red colour visible.	Violence.
57	Fireman. Neck fractured. Severe injury of nose. Hair, chest, and arms scorched. Lips bright pink. Under epidermis of hands also bright pink. Body was found under a fall, and the fracture of neck, &c., evidently occurred after death.	Carbon monoxide poisoning.

The following are the appearance observed in the case of two of the horses examined. It appears unnecessary to give details of all the cases, as they mostly resembled one another closely.

Number.	Description.	Cause of Death
6	From stable on west side of No. 8 pit. No burns. Several slight bruises. Tail slightly singed. Muscles and subcutaneous tissue bright carmine-red. Stomach and intestines pink or carmine-red in parts where blood was visible. Liver light pink. Spleen very dark. Lungs mottled black, and bright carmine-red, not abnormally congested; and on section no liquid exuded. Windpipe carmine-red on internal surface, and containing a few grains of coal dust, but quite clear. Blood of heart dark cherry-red. Samples taken from right and left ventricles, and from spleen.	Carbon monoxide poisoning.
10	From stable on east side of No. 8. pit. Coat much singed. Muscles and subcutaneous tissue bright carmine-red. Intestines pink, with bluish-pink veins. Liver pink. Medulla of spleen pink. Cortex black. Spleen contains little blood. Lungs mottled carmine-red and black; not congested. Bronchi quite free of liquid or dust.	Carbon monoxide poisoning.

ANALYSIS OF THE BLOOD OF THE MEN AND HORSES.

In the samples of blood examined, the method of analysis employed was a modification of that which I recently described in connection with experiments on the action of carbon monoxide on man.* A carmine solution was first prepared of such strength (about ·01 $^{\circ}/_{\circ}$) that when it was added in a certain proportion (about 2½ of carmine to 2 of blood) to a 1 per cent. solution of normal human blood (prepared with a capillary pipette from a drop of my own blood) the pink tint of 1 per cent. human blood saturated with carbon monoxide (or coal gas) was exactly reproduced in both depth and quality. The blood to be examined was now diluted with water until its *depth* (not quality) of tint was equal to that of 1 per cent. human blood saturated with carbon monoxide. 2·0 cc. of this diluted blood were now measured off from a burette into a narrow test-tube. A tube of exactly equal width was partly filled with the saturated 1 per cent. human blood, and carmine solution was added from a burette to the first tube until the tints of the two tubes were exactly equal. It is evident that the less the proportion of carmine solution which required to be added the higher must be the saturation of the hæmoglobin of the blood under examination. For an account of the method of calculating the exact percentage saturations, I must refer to the paper just mentioned. After a little practice there is no difficulty in carrying out the determinations, which may be repeated as often as necessary where there is any doubt.

In examining the samples from Tylorstown explosion I found that the blood had, to a slight extent, lost its power of changing colour when saturated with carbon monoxide. The saturated solution had a slight yellowish tinge as compared with that of normal human or horse's blood solution saturated in the same way. Evidently the hæmoglobin had been to a slight extent decomposed, a derivative possessing a yellowish colour (in dilute solution) being formed. This partial decomposition might be due either to putrefactive changes, or to the inhalation of sulphurous acid present in the after-damp (*see* p. 21). To test the former hypothesis, I repeated the analyses of the human blood some days later, when putrefaction was still further advanced. The results were, however, exactly the same, so that it does not seem likely that the change was due to putrefaction. Accordingly as the standard for comparison is 1 per cent. normal human blood saturated with carbon monoxide or a similarly saturated solution, of equal *depth* of colour of the blood under examination, the result of each analysis varies somewhat. The results calculated for the latter standard of comparison are therefore given in parentheses along with those for the former standard. Future investigation must determine which of the two results is the more correct as expressing the actual percentage saturation of the hæmoglobin with carbon monoxide.

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* Journal of Physiology, Vol. XVIII., p. 431.

PERCENTAGE SATURATION OF THE HÆMOGLOBIN WITH CARBON MONOXIDE.

—	External Jugular Vein.	Heart.		Spleen.
		Right Side.	Left Side.	
Body No. 12 - -	79 (86)	—	—	—
,, ,, 44 - -	79 (86)	—	—	—
,, ,, 42 - -	0	—	—	—
Horse ,, 1 - -	20·5 (26)	—	—	—
Mule ,, 1 - -	59 (62)	—	—	—
Horse ,, 2 - -	—	0	—	—
,, ,, 3 - -	—	77 (84)	77 (84)	—
,, ,, 6 - -	—	62 (75)	62 (75)	59 (68)
,, ,, 7 - -	—	—	—	45

The appearances of the internal organs in the case of horses Nos. 3, 6, and 7 were very much alike. In horse No. 2 (p. 6) no pink colour was anywhere visible.

APPENDIX B.

NOTES on the EFFECTS of AFTER-DAMP at the ALBION COLLIERY EXPLOSION, by J. SHAW LYTTLE, M.D.

The explosion occurred on Saturday, 24th June 1894, shortly before 4 o'clock in the afternoon. Exploring parties were soon formed, and I went down in the third cage, about 6 o'clock. I proceeded first along Cilfynydd level, where some much burned and mutilated bodies were found, and where the largest fall of roof had taken place. The first person seen alive was Thomas Howells, who was found partly conscious in a man-hole, or recess, on the level near the head of Pantddu Dip. On turning to the left into the dip, one of the next seen alive was a boy named Dobbs, and about 90 yards further along was Griffith Bumford, who was standing up against the side, and seemed quite dazed. He knew no one, could not articulate, and when some stimulant was held to his lips he did not comprehend what it was for. I saw some men lying on the ground who had the appearance of being in an ordinary epileptic attack, and were frothing at the mouth. One man was tossing from side to side, and striking his head against the ground; another was in a sitting posture, and groaning terribly. At this spot, about 200 yards from the head of the dip, a number of the living were close together, and their groans could be heard from some way off. Owing to the dim light, and the men being covered with coal dust, I was unable, with the above exceptions, to distinguish the different individuals in the list which follows. Only two or three of them were able to swallow the stimulants offered to them. Along this dip about 30 dead bodies were found, most of them being of men who had been working further inwards, and had been able to get so far on their way to the shaft before they were overcome. Groups of living and dead were distributed almost alternately. Further inwards, at the working places, two living horses were found that were in no way affected either by the explosion or the results of it.

Mr. D. C. Williams, my assistant, who descended in the same cage with me, went along Grover's level on the other side of the shaft. When about 100 yards from the pit bottom he found two men sitting together who were burned about the hands and face. They drank greedily the water offered to them, and continually asked for more. At Dudson's heading he found another man, sitting between the rails. He did not answer questions, but seemed to suffer from great thirst. About two yards further on was another man with both arms under his horse, and fractured. He seemed conscious, and cried out incessantly for water. Another man, who was with the two last-mentioned, between two falls, died almost immediately. Speech was considerably affected in all cases. Mr. Williams was much struck by the fact that all these men, when taken out of the pit, seemed to lose consciousness.

Stretchers were sent down the pit, and the living sent up with the least possible delay, the first reaching the top by 7.30, and the last by 10 o'clock. Those who were identified were sent immediately to their own homes, and the others were taken to an improvised hospital on the colliery premises.

Owing to the terrible situation of affairs, and the multiplicity of my own duties, it was, of course, impossible at first to make any record of observations; and I regret that in so many instances the following clinical notes are very incomplete.

No. 1, aged about 50.—When seen in hospital on Saturday night he was unconscious; breathing stertorous, and profuse perspiration. At 1 a.m. he was carried home, a distance of two miles. At 11 a.m. he was still unconscious, face pale, profuse perspiration, and stertorous breathing. He died about 3 o'clock.

No. 2, aged about 45.—Symptoms the same as in No. 1, and death occurred about the same time. Shortly before death the temperature was 104°, and the pulse 120.

No. 3, aged 27.—Taken home unconscious. When seen at 5 a.m. next morning he was still unconscious, and had the appearance of apoplexy. Face flushed, eyes injected, copious perspiration, stertorous breathing. Died about 12 p.m.

No. 4, aged 40.—Taken home unconscious. Symptoms as in No. 1. Died about mid-day on 25th.

No. 5.—Brought up unconscious. Epileptiform seizures occurred almost continuously, and four persons were holding him during the night. On the morning of the 25th he recognised his brother, and could answer to his name all day. On the morning of the 26th he was worse, but seemed still partly conscious. Temperature, 105°. On the 27th he was much worse, and totally unconscious. In the morning, temperature 104°, pulse 130, respiration 34, and epileptiform twitchings of the limbs. When I saw him in the evening, with Dr. Haldane, he was totally unconscious; pulse 130 and weak, temperature 104°·5, respirations 30. Clonic contractions of the limbs were occurring almost constantly; eyes directed to one side; much perspiration. Blood examined spectroscopically by Dr. Haldane, who found no trace of carbon monoxide. Died about 1 p.m. on the 28th.

No. 6, aged 21.—Brought up unconscious; no epileptiform seizures. Began to recover consciousness on night of 24th. Partly conscious next day, but very restless at night. On 26th nearly unconscious; pulse only 38, and easily compressible. Next day pulse and general condition about the same. When seen by Dr. Haldane in the evening, pulse 38, respirations 17, almost comatose. Blood showed no trace of carbon monoxide on spectroscopic examination. On 28th partly conscious, pulse 46 to 58. On 29th pulse 86 to 90; temperature, 100°·5 to 100°·9; unconscious. On 30th continued still unconscious. When spoon put between his teeth he clenches them and holds it fast; spasms of muscles of face and limbs; opisthotonus also observed. At 12 p.m. pulse 104°; temperature 102°. On July 2nd looks a little better; pulse, 122°; temperature, 100°·2 to 100°·5; respirations 26 and shallow. Lies quite motionless; winces when light held to face. Opisthotonus again observed during night. Next day seemed worse. Skin over sacrum gangrenous. Compressed oxygen administered without effect; gradually sank, and died on July 4th, 11 days after the explosion.

No. 7 (Griffith Bumford).—Found standing in a dazed condition, as described above. He soon recovered, and was able, with assistance, to walk home. Next day his mind was still confused, but he gradually improved. He suffered for some time from headache and giddiness, and had, for a few days, no recollection of the events of the explosion. By the time of the inquest, however, he was able to recollect much of what had happened. He was working on Mordecai's level, about 600 yards from where he was found, and gave the following account of what occurred :—

"I heard a sound like thunder, the biggest I ever heard. I heard two sounds, with scarcely any interval, each just the same noise. I thought it was an explosion, and stood where I was. I heard the door between us and the engine dip parting open and shut with a bang; the level directly after (less than a minute) was filled up with dust, and our lamps went out. There were four of us together, and two more inside. I think I saw a shade of flame in the dust of a blueish colour. It was coming along above us, near the roof. I was standing up; the place was about 7 feet high. We started off then to walk to Pantddu dip. The flames and dust passed over us, and we came out. In Pantddu dip the after-damp was strong, and I recollect no more till I came to myself, when Dr. Lyttle and Harry Watkins were with me at the air-bridge."

No. 8 (Jenkins).—Very slightly affected from the beginning. He was found near the head of Pantddu dip, having made his way into a man-hole.

No. 9 (Dobbs, aged 16).—When the explosion took place he had followed Jenkins to the head of the dip, when he fell down. He had no epileptiform seizures, but was brought up quite comatose, and remained unconscious till the night of the 25th, when consciousness began to return. He was occasionally delirious. On the 26th he was able to go out, but was comatose again at night, and remained so till the afternoon of the 28th, when he appeared like a person suffering from opium poisoning. I roused him by flagellation, gave him some strong coffee, and had him taken out. When seen outside afterwards he looked stupid, but understood more or less what was said to him. On July 1st he was still drowsy, and in a state of melancholic stupor. He had still no recollection of what had taken place, and was not aware of the death of his father, whose body was also found in Pantddu dip. The funeral which he had seen had made no impression on his mind. From this date a constant and gradual improvement occurred, but on August 1st he had still no recollection whatever of the explosion.

No. 10.—When I saw him on Pantddu dip he seemed not unconscious, and was crying out, and making a great deal of noise. Next day (the 24th) he was quite sensible, and was out on the 25th. For some days he seemed somewhat morose in temper. On the 30th I observed well marked choreic movements. On August 1st he seemed very much better, and said he could work, but that when he attempted to read he saw double.

No. 11, aged about 18.—Was brought up unconscious. While in the temporary hospital he could not be got to answer questions. On account of violent muscular movements he required to be held by two persons. On the morning of the 25th he was able to answer questions slowly, and gradually improved. On the 28th he was walking about the room, but still very stupid. On the 29th he was worse, and very drowsy, but could still be roused. Pulse 66. On the 30th he could not be got to answer questions, and when a spoon was put into his mouth, clenched his teeth. On July 1st same condition. Pulse 52. Respirations 14. Next day he looked better, and answered indistinctly when spoken to. On July 3rd much brighter, but continued to be drowsy, and to go off to sleep when left alone. Slight choreic movements. After this he improved continuously, and left for home on the 7th.

No. 12 (Thomas Howells). Found partly conscious in a refuge place on Cilfynydd level. Slightly burned and bruised on side of head and face, and on arms. He was very sick, and was vomiting in the cage when brought up, but otherwise was very slightly affected, and remembered seeing the flame of the explosion.

In addition to the above, who were found, with the exception of No. 12, on Pantddu dip, four other men were brought out alive from Grover's level. They had all received extensive burns, and none of them survived beyond the fifth day. Their symptoms (delirium, &c.) were probably due to burns and not merely to after-damp.

The following accounts were given by rescuers of the symptoms which they experienced:—William Garnett, who went down in the first cage, described the smell along Grover's level as "sulphury"; his eyes were smarting very much. The further in he went, the more faint and dizzy did he become, and he felt as if he would like to sleep. At one time he had to sit down, and was helped to a safe place.

John Jenkins went first to Bodwenarth incline, off Cilfynydd level. He felt his eyes smarting very much, and along the incline he felt so weak that he was almost overcome, and required assistance to be brought back. Another man with him was also affected.

Several others experienced similar symptoms. I myself noticed some smarting of the eyes, and suffered considerably from thirst, as also did Mr. Williams, and others.

ADDENDUM.

BRANCEPETH EXPLOSION.

April 30th, 1896.

An explosion, involving the loss of 20 lives, occurred at Brancepeth Colliery (near Durham) on the morning of April 20th. With a view of ascertaining whether the causes of death were similar to those at the Tylorstown explosion, I visited the colliery two days after the explosion. The colliery is not a fiery one, but the dust in some parts of it appears to be very sensitive (*see* Mr. Henry Hall's Report to the Commission on Coal-dust Explosions, p. 5; also the Minutes of Evidence relating to an explosion in a hopper at Brancepeth).

Along with Mr. R. E. Brown, Medical Officer to the colliery, I examined the bodies which had been recovered at the time of my visit. In one case death had been due to violence; in the other eight to carbon monoxide poisoning. The appearances were on the whole very much the same as in the Tylorstown explosion. In two cases there were no marks of burning; in the other six the exposed parts were superficially scorched. The burning was, on the whole, not so severe as in the Tylorstown explosion, the men having been much more protected by clothes. In one case, however, the backs of the legs had been slightly burnt through woollen stockings, and the stockings themselves were scorched and easily torn. One case presented the appearance of dusky-red venous congestion of the face and distention of the superficial veins of the chest, noted in bodies No. 19 and 21, at Tylorstown.

The eleven bodies, when they were recovered, were examined by Mr. Brown, who kindly furnished me with very complete notes of their appearances. In one case there were marks of great violence (inflicted after death by falls ?) and severe burning, although the actual cause of death, as shown by the colour of the blood, was apparently carbon monoxide poisoning. In the other 10 bodies there were no marks of burns or injuries, and although putrefaction was already far advanced, as shown by greenish discoloration, &c., Mr. Brown was in every case able to recognise the characteristic pink colour of the lips, skin, &c. A scarf was found tied round the mouth in two of the bodies.

It thus appears that of the 20 men killed in this explosion, 19 had been poisoned by carbon monoxide, and one had been killed instantaneously by violence. Of those killed by carbon monoxide one had (before death ?) received fatal injuries, while six had been superficially burnt, chiefly about the hands and face.

The following are notes of the appearances in three of the cases:—

No. 1. Hair of head burnt short, but beard only slightly singed. Much coal-dust on face; lips red; slight cut on right side of head. Body not burnt, but clothes seem somewhat singed. Epidermis loosened on backs of hands; skin white and apparently uninjured underneath. Nails pink.

No. 2. Eyebrows, most of hair, and most of eyelashes singed off. Face washed from coal-dust, and is pale on the whole, but mottled with patches of red, apparently due to burning. Lips pale pink. Tongue also pale. Body not burnt, and clothes intact. Epidermis of hands and lower part of arms loosened, but still adherent on palmar surface. Under epidermis skin pale, but bright pink colour seen towards palmar surface. Blood from external jugular vein found to be 83 per cent. saturated with carbon monoxide (two analyses gave exactly the same result). On complete saturation the blood gave exactly the same tint as normal blood similarly treated.

No. 3. Face placid and quite life-like, with slight red flush. Lips of a natural red colour. Slight contusion on forehead. Hair not singed, and no marks of burning anywhere. Chest slightly flushed with pink. Hands of a life-like reddish colour. Nails pink.

No. 4. (Recovered on sixth day after explosion.) Face and head very much swollen, and dark green in colour. Tongue protruding, and bright pink. Internal surface of lips pink. Bright pink beneath epidermis of hands. Putrefaction over chest and abdomen. No singeing or mechanical injuries.

MICKLEFIELD EXPLOSION.

May 3rd.

On April 30th an explosion occurred at Micklefield Colliery, and resulted in the loss of about 60 lives. The pit is not a fiery one, but is dry and rather dusty. The dust appears to be very sensitive (*see* Mr. Henry Hall's Report, p. 7).

I examined the bodies, 46 in number, recovered up to the afternoon of May 2nd. Carbon monoxide poisoning had apparently been the actual cause of death in every case. In 67 per cent. of the bodies there were no burns or injuries. In 9 per cent. there were slight burns, which did not seem of such a nature as to endanger life. The remaining 24 per cent. were severely burnt, and nearly all of these men would have died apart from the effects of carbon monoxide. The burns were in four cases much deeper and more severe than any of those observed at Tylorstown or Brancepeth. The deep skin had a parchment-like consistence at parts, so that it was evidently more or less destroyed. In two of these cases there were also mechanical injuries sufficient to have caused rapid death. In 15 per cent. of the bodies the appearances were those of acute poisoning by air containing about 2 or 3 per cent. of carbon monoxide, as in bodies No. 19 and 21 at Tylorstown. In one of these cases the blood of the external jugular vein was found to be 63 per cent. saturated with carbon monoxide (*see* page 23). In a number of cases the lips and skin were very pale, and the appearances seemed to suggest that death had occurred very slowly, and in air containing a very slight amount of carbon monoxide. In one of these cases the venous blood was only 52·5 per cent., and in two others 70 per cent. saturated.

Many of the rescuers were seriously affected by the after-damp. Their symptoms were simply those of carbon monoxide poisoning. Smarting of the eyes was not observed at all by those who gave me information on the subject. The lamps of the rescuers seem never to have been extinguished by the after-damp. From both the symptoms of the rescuers and the appearances of the bodies, I am inclined to think that in this explosion the undiluted after-damp must have contained about 5 per cent. of carbon monoxide.

On the occurrence of the explosion, Dr. Griesbach, Medical Officer to the Colliery, at once obtained a supply of oxygen in cylinders, and this was of great service in treating the rescuers. It was observed, again and again, that the latter became much worse, and even lost consciousness on getting into cooler and fresher air, or coming to the surface (*see* page 19). The administration of oxygen produced very rapid improvement in these cases.

Three of the rescued were severely burnt about the face and hands, the epidermis being covered with adherent coal-dust and loosened in the manner described on page 3. Two of these men were also rendered unconscious by after-damp. They were all removed to Leeds Infirmary, where they appeared to be progressing very favourably.

One man was found alive 56 hours after the explosion. He was beside several companions who were dead. A little way further in a pony was found alive and quite well. I was in the pit at the time when the living man was found, and proceeded to the place with a cylinder of oxygen. His pulse and breathing were fairly good, but he was quite unconscious and his extremities were cold. After covering him up as warmly as possible I administered oxygen for about 20 minutes with a view to rapidly clearing the blood of most of the carbon monoxide. The oxygen was given by simply allowing a good stream of oxygen to pass through a tube into the mouth, and compressing the nostrils during each inspiration. He was then brought on a stretcher as quickly as possible to the shaft and up to the surface, where he was placed with warm bottles beside him in front of a good fire until the extremities were warm. On examination his blood was found to be 20 per cent. saturated with carbon monoxide about half an hour after he had been got out of the pit. The temperature in the axilla was then normal and his condition seemed to have improved, though he was quite unconscious. As soon as his extremities were warm he was removed to Leeds Infirmary, where, however, he died next day, in spite of every care.

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1. VI. 96.

THE CAUSES OF DEATH IN COLLIERY EXPLOSIONS.

REPORT

TO THE

SECRETARY OF STATE FOR THE HOME DEPARTMENT

ON THE

CAUSES OF DEATH IN COLLIERY EXPLOSIONS AND UNDERGROUND FIRES,

WITH SPECIAL REFERENCE TO THE

EXPLOSIONS AT TYLORSTOWN, BRANCEPETH, AND MICKLEFIELD.

BY

JOHN HALDANE, M.D.

Presented to Parliament by Command of Her Majesty.

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