Bulletin 277

DEPARTMENT OF COMMERCE
HERBERT HOOVER, Secretary

BUREAU OF MINES
SCOTT TURNER, Director

SAFETY IN COAL MINING

{A HANDBOOK}

BY

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PRICE 25 CENTS

Sold only by the Superintendent of Documents, U. S. Government Printing Office
Washington, D. C.

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON
1928

PREFACE

This handbook, Safety in Coal Mining, has been prepared at my request by the chairman of the mine safety board of the Bureau of Mines. The purpose of the handbook is to make available in convenient form a concise statement of practices and methods recommended by the bureau for the increase of safety in coal mining.

Rapid growth in the use of machinery for cutting and loading coal, longer haulage ways, and the wider use of mechanical haulage have contributed toward economy in mining by making possible a larger output of coal without a corresponding increase in the number of workers. At the same time this mechanicalization of the mines has been accompanied by increased hazards from falls of roof and coal and from accidents in transporting the coal from the face to the tipple. Incidentally, also, the machines have introduced new hazards peculiar to themselves, although these hazards can not be classed among the major causes of mine accidents.

Progress in accident prevention is indicated by either a larger output per accident or fewer accidents per employee; double progress is realized when increased production per accident accompanies a reduction in the accident rate per employee.

It is hoped that this publication will prove helpful to safety engineers, mine owners, mine employees, and others in their endeavor to obtain the Nation's necessary fuel at a minimum cost in life and limb. The bureau plans to revise the handbook from time to time as developments in the industry, and further study and research, seem to warrant.

SCOTT TURNER, *Director.*

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SAFETY IN COAL MINING: A HANDBOOK

By George S. Rice

INTRODUCTION

Mining is an occupation more hazardous to life and limb than many others because it is carried on underground and hence in confined places. Besides the possibility of those accidents that may happen in surface industries using machinery and mechanical transport, there are the additional and greater dangers of falls of ground from the roof or sides, not only in the working places but also along the roads the miners use in going to and from work—dangers that are especially acute in pitching working. There are also the dangers inseparable from the use of explosives. In the United States in 1925 the fatality rate for all metal mines per thousand 300-day workers was 2.99 as compared with 1.78 for quarries, 1 for ore-dressing plants, and 0.64 for smelters. In comparison with metal mining, coal mining presents additional dangers because more or less dangerous amounts of inflammable gas enter the workings. In 1925 the fatality rate for coal mines per thousand 300-day workers was 4.65, as compared with 2.94 for copper mines, 3.83 for gold and miscellaneous metal mines, 2.54 for iron mines, and 3.32 for lead and zinc mines.

To prevent or decrease accidents in mining, especially coal mining, is a far more complicated problem than in surface industries, even in those that are hazardous, because machinery guards and the separation of different elements of danger are more easily arranged aboveground and human errors may endanger only one or a few, instead of the hundreds of lives endangered by an error or a careless act that causes an explosion or a mine fire.

Because the prevention of accidents in coal mines is difficult, the various coal-mining countries and the different States of this country have adopted comprehensive codes of regulations. The more progressive mines have not been satisfied to accept the minimum requirements for safety that are specified in the State code under which they come and have adopted additional rules of their own.

At the beginning of this century accidents became increasingly numerous because of natural conditions due to increasing depth, more gas entering the mines, and roof pressure growing heavier, and also because of the growing use of electric power and, in some districts, of blasting off the solid instead of hand mining. Disastrous explosions happened so frequently that in 1908, as the result of a series of particularly bad coal-mine disasters in the preceding year, Congress was petitioned to have the Federal Government investigate the causes of coal-mine explosions and other accidents. In consequence, a technologic branch of the United States Geological Survey was established to undertake the work. Two years later the work was transferred to the Bureau of Mines, which was established to conduct investigations for the increase of safety in all kinds of mining and mineral preparation and to investigate the economic problems of all the mineral industries, including metallurgy, the mining and preparation of nonmetallic minerals, and the petroleum industry.

This report deals solely with accidents in coal mines and with the means of prevention that have been determined and officially approved by the bureau or have been tentatively suggested by certain members of the bureau. Mining, mechanical, and electrical engineers, chemists, physicists, and statisticians who have had experience in problems of mine safety have been consulted, but where the report deals with questions and policies not officially as yet decided on it necessarily reflects to a certain extent the views of the writer.

The report aims to give only concise recommendations based on mine investigations and on laboratory work. References will be made to more complete information when that has been published.

ACKNOWLEDGMENTS

Valuable information for use in this handbook has been freely given by many members of the bureau and has been thankfully received by the author. To make personal acknowledgments to all is not feasible, but those named below have approved those parts that deal with subjects in which they are concerned technically and administratively: O. P. Hood, chief mechanical engineer; L. C. Ilsley, electrical engineer; D. Harrington, chief engineer, safety division; J. W. Paul, senior mining engineer; R. R. Sayers, chief surgeon (physiological investigations); A. C. Fieldner, chief engineer, experiment stations division; Charles E. Munroe, chief explosives chemist; G. St. J. Perrott, physical chemist (in charge of explosives laboratory and testing of explosives); S. P. Howell, explosives

engineer; William Yant, associate chemist (gas laboratory); J. J. Forbes, chief engineer, safety instruction section; and W. W. Adams, mine-accident statistician.

Special indebtedness is acknowledged to the late Samuel Sanford, editor of the bureau since its organization and a man of profound knowledge and sympathetic understanding, who gave valuable service in the preparation of this handbook.

ACCIDENTS IN COAL MINES, BY CAUSES

Table 1, compiled by W. W. Adams, shows for a 10-year period, 1915 to 1924, the percentage of men killed yearly by 21 main causes, above and below ground, at coal mines (including anthracite mines) in the United States; it also gives the actual number of deaths from each cause in 1924 and 1925.

TABLE 1.—*Fatalities by causes, 1915–1924 and 1925* [1]

	Per cent of total			Number of fatalities	
	1915–1924	1924	1925	1924	1925
Underground:					
1. Falls of roof (coal and rock)	42.2	39.2	43.7	941	977
2. Falls of face or pillar coal	5.5	5.0	4.6	121	103
3. Mine cars and locomotives	17.1	14.7	16.1	354	361
4. Explosions of gas or dust, local	3.6	3.2	3.8	536	345
4. Explosions of gas or dust, major	8.1	19.1	11.7		
5. Explosives	5.7	4.1	4.6	99	102
6. Suffocation from mine gases	.5	.6	.4	13	8
7. Electricity	3.4	3.3	3.8	80	84
8. Animals	.3	.2	.2	4	5
9. Mining machines	1.0	1.3	1.6	30	35
10. Mine fires (burned, suffocated)	.3	.1	.4	2	10
11. Other causes	2.7	2.3	1.9	55	43
Total underground	90.4	93.1	92.8	2,235	2,073
Shaft:					
12. Falling down shafts	3.9	.6	.7	15	15
13. Objects falling down shafts or stope	.3	.2	.1	5	3
14. Cage, skip, or bucket	.7	.3	.4	7	10
15. Other causes	.1	.1	.3	2	6
Total shaft	2.0	1.2	1.5	29	34
Surface:					
16. Mine cars and mine locomotives	2.4	2.1	1.1	50	24
17. Electricity	.5	.7	.7	16	16
18. Machinery	1.1	.3	.4	8	9
19. Boiler explosions or bursting steam pipe	.2	.0	.1	0	2
20. Railway cars and locomotives	1.0	.8	.7	20	16
21. Other causes	2.4	1.8	2.7	44	60
Total surface	7.6	5.7	5.7	138	127
Grand total, top and bottom workers	100.0	100.0	100.0	2,402	2,234

Killed per thousand 300-day workers in 1925, 4.65; killed per 1,000,000 tons of coal produced in 1925, 3.84; number of men employed underground in 1925, 627,109; number of men employed surface and underground in 1925, 748,805.

[1] Adams, W. W., Coal-Mine Fatalities in 1926: Bull. 283, Bureau of Mines, 1927.

During the 10-year period, as the table shows, more than 92 per cent of the fatalities were underground or in shafts. The first 5 causes of fatalities underground cover 82 per cent of all fatalities, and falls of roof and coal include 48 per cent of all accidents, or 52 per cent of all fatalities underground. Explosions in the 10-year period caused only 12 per cent of all accidental deaths; but, on the other hand, in 1924 they caused 22 per cent.

COMPARISON OF ACCIDENT RATES IN MINES

Two general methods of comparing coal-mine accident statistics are used: (1) By annual accident rates per thousand employees, or (2) by the number of accidents in relation to the output of coal.

Under the first method the comparisons are made on the basis of the deaths or fatalities in the respective occupation or mine, per 300-day men employed, either (*a*) in the particular occupation, or (*b*) in all occupations at the mine (in other words, the total number employed). An alternative to using the number of men employed for death or injury rates is to use the shifts worked per annum or hours worked per annum.

The second method is to compare the number of accidents on the basis of the yearly deaths or injuries (in the respective occupations, mines or mining districts, or States) per million tons of coal produced, or the reciprocal, tons mined per death or injury.

The first method is ordinarily used and, in fact, is the only way of comparing the accident rates for the different mining conditions in various coal fields; it does not, however, consider the efficiency of the miners or the organization and mechanicalization of mining—for example, the employment of an unnecessary number of men on dead work, or the noninstallation of labor-saving devices and methods.

The second method combines but leaves uncertain the relative importance in hazard rating of three factors: (1) Natural mining conditions that affect ease of mining; (2) combined efficiency of men and machinery employed in producing coal; and (3) relative care or carelessness of management and miners. It is obvious, for example, that a thin or a pitching bed, or one with many rolls or with a bad roof, must employ more men per unit of output than a mine in a level thick bed, hence accident rates on a tonnage-production basis do not necessarily reflect the relative care taken.

Neither the first nor the second method gives the complete picture, but the first method better indicates the degree to which voluntary safety rules or State regulations have been observed.

Table 2 uses the second method, the number of deaths in comparison to the gross production, for comparing fatality rates among coal miners in the different States. Figures are also given to show the average daily production per man per day in 1925.

TABLE 2.—*Production of coal and number of men killed per million tons of coal produced during 1925 and the 10-year period 1916–1925* [1]

State	1925: State production, tons of 2,000 pounds	1925: Daily production per man, tons of 2,000 pounds	Number killed per million tons: 1925	Number killed per million tons: 1916–1925
Alabama	20,004,395	3.0	8.05	6.10
Alaska	82,868	2.2		
Arkansas	1,220,039	3.0	10.66	6.48
California, Idaho, and Nevada	12,625	1.7		6.91
Colorado	10,310,551	4.1	5.43	6.99
Georgia and North Carolina	131,327	1.9	[2] 403.57	55.97
Illinois	66,909,359	5.3	1.79	2.40
Indiana	21,224,966	5.9	4.85	3.10
Iowa	4,714,843	3.0	4.03	3.77
Kansas	4,524,251	3.4	2.43	4.33
Kentucky	55,068,670	4.7	3.52	3.31
Maryland	2,694,572	3.6	4.45	3.81
Michigan	808,233	2.8	6.19	4.04
Missouri	2,694,215	3.2	4.08	2.52
Montana	3,043,686	6.6	1.97	3.95
New Mexico	2,556,851	3.7	7.04	10.25
North Dakota	1,324,620	6.6	4.53	2.99
Ohio	28,034,112	4.7	3.39	3.24
Oklahoma	2,325,840	2.7	5.59	6.94
Pennsylvania (bituminous)	136,928,019	4.4	2.26	2.66
South Dakota	14,447	2.1		
Tennessee	5,454,011	3.1	4.77	3.74
Texas	1,008,375	3.2	1.98	1.76
Utah	4,690,342	5.9	5.12	8.81
Virginia	12,799,443	3.7	3.75	3.72
Washington	2,537,890	3.5	13.00	7.39
West Virginia	122,380,959	4.9	3.91	4.32
Wyoming	6,553,232	5.9	2.59	5.91
Total (bituminous)	520,052,741	4.5	3.53	3.56
Pennsylvania (anthracite)	61,817,149	2.1	6.47	5.95
Total	581,869,890	4.0	3.84	3.91

[1] Compiled from Bulletin 283, previously cited. [2] Mine explosion at Coal Glen, N. C.

ACCIDENT RATES OF MINING AND OF SURFACE INDUSTRIES

Table 3 compares fatalities in coal mines per thousand 300-day workers in the typical years 1915, 1919, 1923, and 1925 with those in the mining of various metals and in two surface (metallurgical) industries. It shows that coal mining is more hazardous than metal mining, which in turn is much more hazardous than the two surface industries. The table also gives the number of 300-day metal miners per thousand killed or injured and indicates that the liability to an injury is 40 to more than 100 times greater than that to a fatality.

As yet no general statistical figures are available for coal-mine injuries in the United States. The British coal-mine statistics for 1924 on injuries causing disabilities of more than 3 days indicate a ratio of 163 injured to 1 killed, and in 1925 of 158 injured to 1 killed. If a similar but lower ratio (to be conservative) were applied to coal mining in the United States (for example, 100 injuries to 1 fatality), mortality records for 1925 would indicate the probability of 223,000 injuries of all kinds for the year. In other words, about 30 per cent of all mine employees would be injured in some way during that year.

TABLE 3.—*Number of men killed and injured per thousand 300-day workers in 1915, 1919, 1923, and 1925* [1]

	1915		1919		1923		1925	
	Killed	Injured	Killed	Injured	Killed	Injured	Killed	Injured
Coal mines	4.44	(2)	4.27	(2)	4.39	(2)	4.65	(2)
All metal mines	3.89	249	3.47	234	3.01	275	2.99	284
Copper mines	3.72	322	3.54	310	3.11	349	2.94	351
Gold and miscellaneous mines	4.79	201	4.41	191	3.93	299	3.83	307
Iron mines	2.88	234	3.09	202	2.38	150	2.54	159
Lead and zinc mines	5.37	238	4.13	292	2.73	496	3.32	468
Ore dressing	1.57	110	1.48	122	1.62	172	1.00	131
Smelters	1.05	158	1.09	141	.64	131	.64	114

[1] From Adams, W. W., Coal-Mine Fatalities in 1926: Bull. 283; Bureau of Mines, 1927.
[2] Figures not available.

Table 17 of Bulletin 283 gives details of the principal causes of fatal accidents in coal mining and is reproduced below as Table 4.

TABLE 4.—*United States: Coal-mine fatalities by detailed causes, 1917 to 1926*

Cause	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926
NUMBER KILLED UNDERGROUND										
1. Falls of roof (coal, rock, etc.):										
(a) At working face	707	764	649	640	519	518	783	665	728	812
(b) In room or chamber	178	179	122	188	214	115	120	140	149	158
(c) On road, entry, or gangway	164	225	166	174	183	144	133	128	92	115
(d) On slope	8	14	17	10	9	11	13	8	8	8
Total	1,057	1,182	954	1,012	925	788	1,058	941	977	1,093
2. Falls of face or pillar coal:										
(a) At working face	151	95	129	93	86	106	97	104	93	107
(b) On road, entry, or gangway	22	17	24	29	14	14	12	17	10	13
Total	173	112	153	122	100	120	109	121	103	120
3. Mine cars and locomotives:										
(a) Switching and spragging	6	15	12	6	13	3	5	5	7	13
(b) Coupling cars	7	11	6	13	18	4	12	7	5	5
(c) Falling from trips	29	36	17	26	11	12	15	18	23	20
(d) Run over by car or motor	187	203	151	164	120	135	144	117	121	160
(e) Caught between car and rib	122	113	105	99	98	105	121	92	106	90
(f) Caught between car and roof while riding	20	27	22	18	26	24	26	29	16	18
(g) Runaway car or trip	67	68	42	43	32	34	51	39	41	38
(h) Miscellaneous	50	33	27	39	23	24	39	47	42	87
Total	488	506	382	408	341	341	413	354	361	431
4. Explosions of gas or coal dust:										
(a) Due to open light	234	57	88	86	81	121	163	372	106	127
(b) Due to defective safety lamps	------	2	22	------	5	7	1	1	1	3
(c) Due to electric arc	22	7	19	10	2	112	154	52	10	54
(d) Due to shot	13	36	30	31	15	55	36	21	84	51
(e) Due to explosions of powder [1]	13	4	4	17	15	12	3	4	0	3
(f) Miscellaneous	78	23	28	16	8	4	15	86	135	184
Total	360	129	191	160	126	311	372	536	345	422

[1] The cause of the fatalities due to explosions of powder, as given by some State statistical bureaus, is open to question. Some of the explosions of gas and dust attributed to this cause should possibly be grouped under "(d) Due to shot," of item 4, "Explosion of gas or dust" in Table 4.

TABLE 4.—*United States: Coal-mine fatalities by detailed causes, 1917 to 1926*—Continued

Cause	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926
NUMBER KILLED UNDERGROUND—con.										
5. Explosives:										
(a) Transportation	6	4	97	3	7	------	5	------	9	------
(b) Charging	5	13	14	4	10	5	5	5	1	4
(c) Suffocation	10	4	3	4	18	5	9	1	3	5
(d) Drilling into old holes	1	2	------	3	4	1	6	8	6	1
(e) Striking in loose rock or coal	------	1	------	------	3	1	1	------	------	------
(f) Thawing	------	------	------	------	------	------	------	------	------	------
(g) Caps, detonators, etc	2	3	3	3	2	3	3	2	2	1
(h) Unguarded shots	2	------	3	2	9	3	8	9	3	4
(i) Returned too soon	8	18	5	12	12	11	16	13	9	9
(j) Premature shot	44	44	56	59	41	32	35	37	36	32
(k) Sparks from match, lamp, or candle	5	13	7	5	9	7	4	1	5	3
(l) Delayed blast	5	4	2	14	13	7	6	9	6	10
(m) Shot breaking through rib or pillar	10	9	6	1	2	7	4	3	8	7
(n) Miscellaneous	12	20	10	21	12	11	13	11	14	19
Total	110	135	206	131	142	93	115	99	102	95
6. Suffocation from mine gases	8	15	11	18	9	9	9	13	8	14
7. Electricity:										
(a) Direct contact with trolley wire	46	55	39	29	35	29	36	45	35	33
(b) Bar or tool striking trolley wire	2	4	2	3	3	3	4	1	1	2
(c) Contact with mining machine	5	7	4	9	6	3	5	8	11	9
(d) Contact with machine feed wire	16	12	14	10	11	12	12	5	7	6
(e) Contact with haulage motor	4	1	2	3	5	1	------	4	------	2
(f) Miscellaneous	6	9	7	22	20	26	18	17	30	43
Total	79	88	68	76	80	74	75	80	84	95
8. Animals	9	8	2	4	7	5	10	4	5	7
9. Mining machines (other than 7c)	19	17	26	37	18	21	23	30	35	26
10. Mine fires (burned, suffocated, etc.)	2	26	22	8	16	------	------	2	10	1
11. Other causes:										
(a) Fall of person	11	5	6	2	17	7	4	6	5	10
(b) Machinery (other than 9)	2	1	3	1	5	4	6	5	6	5
(c) Rush of coal or gob	22	20	15	9	9	6	13	12	7	7
(d) Falling timber	12	12	23	11	10	8	14	3	2	5
(e) Suffocation in chutes	2	3	2	6	8	------	4	5	2	4
(f) Hand tools, axes, bars, etc	------	------	------	------	3	------	2	------	1	2
(g) Nails, splinters, etc	------	------	1	------	1	------	------	1	------	------
(h) Miscellaneous	21	22	18	16	22	18	31	23	20	23
Total	70	63	68	45	75	43	74	55	43	56
Total underground	2,375	2,281	2,083	2,021	1,839	1,805	2,258	2,235	2,073	2,360
NUMBER KILLED IN SHAFT										
12. Falling down shafts or slopes	21	21	20	27	18	14	22	15	15	13
13. Objects falling down shafts or slopes	12	9	6	8	9	4	3	5	3	6
14. Cage, skip, or bucket.										
(a) Runaway	------	1	8	11	3	1	7	1	------	1
(b) Riding with rock or coal	1	------	1	2	2	------	------	------	------	------
(c) Riding with timber or tools	13	------	1	------	------	------	------	------	------	------
(d) Struck by	6	9	4	4	2	10	5	4	6	4
(e) Miscellaneous	2	7	6	2	2	9	8	2	4	11
Total	22	17	20	19	9	20	20	7	10	16
15. Other causes:										
(a) Overwinding	2	------	------	------	------	------	------	------	1	------
(b) Breaking of cables	2	1	------	------	------	1	------	1	------	------
(c) Miscellaneous	1	4	6	2	------	2	1	1	5	------
Total	5	5	6	2	------	3	1	2	6	------
Total shaft	60	52	52	56	36	41	46	29	34	35

TABLE 4.—*United States: Coal-mine fatalities by detailed causes, 1917 to 1926*—Continued

Cause	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926
NUMBER KILLED ON SURFACE										
16. Mine cars and mine locomotives	74	87	71	54	25	32	36	50	24	30
17. Electricity	17	15	10	17	17	9	8	16	16	16
18. Machinery	46	49	22	25	16	20	26	8	9	9
19. Boiler explosions or bursting steam pipes	8	7	6	4	1	3	------	------	2	------
20. Railway cars and locomotives	36	31	22	24	20	22	24	20	16	20
21. Other causes:										
(*a*) Explosives	13	11	1	11	5	9	10	3	6	2
(*b*) Fall of person	19	12	15	9	9	6	15	7	12	6
(*c*) Falling objects (derricks, booms, etc.)	7	12	9	10	5	2	1	8	5	3
(*d*) Suffocation in chute, bin, or culm	4	4	3	6	1	2	2	------	1	2
(*e*) Falls or slides of rock or coal	3	3	10	9	2	7	10	2	3	2
(*f*) Steam shovels	3	2	2	------	1	5	1	1	1	------
(*g*) Hand tools	------	------	2	1	------	------	1	------	------	------
(*h*) Miscellaneous	31	23	15	25	18	21	24	23	32	28
Total	80	67	57	71	41	52	64	44	60	43
Total surface	261	247	188	195	120	138	158	138	127	118
Grand total	2,696	2,580	2,323	2,272	1,995	1,984	2,462	2,402	2,234	2,513

CHIEF CAUSES OF COAL-MINE ACCIDENTS

The principal causes of the fatal accidents listed in the foregoing tables will be discussed and appropriate recommendations made in the following order, which is not the order of the risk to any individual miner as shown statistically but the relative order of magnitude of the precautions that must be taken by mine managements to abate the respective accidents:

(*a*) Explosions of gas or coal dust.
(*b*) Explosives accidents other than those causing explosions of gas and dust.
(*c*) Mine fires.
(*d*) Falls of ground.
(*e*) Haulage accidents.
(*f*) Electric shocks.
(*g*) Miscellaneous underground, including inrushes of water.
(*h*) Shaft accidents.
(*i*) Surface accidents connected with dumping, screening, and loading coal; also accidents in the power house and shops.

ORGANIZATION, ADMINISTRATION, AND REGULATION

Before taking up the detailed discussion of each of the above groups of accidents it is advisable to bear in mind that abatement of the accidents in any one of the groups involves considerations of four important factors—organization, administration, planning, and discipline. Unless each of these factors receives adequate attention, reasonable freedom from accidents is impossible. Coal mining is admittedly hazardous. The industry has already done much to overcome natural hazards, but far more can be done to lessen injuries and deaths, which are becoming a matter of national concern.

EXPLOSIONS OF GAS OR COAL DUST

Explosions of gas and coal dust, separately or together, have killed thousands of coal miners in this country during the past quarter century. As a matter of fact, fatalities from falls of roof or coal are far more numerous and for the country as a whole occur almost hourly. A fall, however, rarely kills more than one or two men and fatalities from falls get little notice, whereas explosions, some of which kill many men, attract wide attention and are far more dreaded.

Major explosions in this discussion, as in the statistical publications of the Bureau of Mines, are those that cause the death of five or more persons. Fortunately they are rare, and virtually all are coal-dust explosions in bituminous mines. There has been an average of about eight such disasters a year in bituminous mines in the 25 years 1900 to 1924; but the annual toll of fatalities averages 252 and ranges from 868 in 1907 to 16 in 1921. Peaks were reached in 1924 (444 deaths) and 1925 (244 deaths).

Local and shot firers' explosions of gas and bituminous dusts have been vastly more frequent, but a number of them have not killed anyone because they were started by shots fired electrically from outside the mine; however, the yearly average number of deaths from such explosions during the 10 years ended 1925 is 87 men. This figure includes deaths from local explosions of gas in the Pennsylvania anthracite district, where the dust is not explosive. Some explosions that were local might have become great disasters if the condition of the coal dust or the proportion of gas in the air current had happened to favor propagation of the initial explosion.

One fact must be borne in mind—without adequate ventilation and safeguards from ignition underground coal mining on a large scale would hardly be possible to-day. Precautions against explosions are therefore a primary requirement in coal mining and demand consideration even beyond that given falls of roof, which kill far more men. It is believed that major explosion disasters can be eliminated by the preventive measures described herein.

METHODS OF PREVENTING MINE EXPLOSIONS

1. Ventilation, to dilute and carry inflammable gases out of the mine; suitable methods of determining the proportion of such gases in the mine air, to guide the management in furnishing adequate ventilation in every part of the mine.

2. Rock-dusting, to prevent ignition and propagation of explosions of bituminous coal dust.

3. Permissible explosives, to prevent ignition of gas or bituminous coal dusts. Shots of black blasting powder dynamite have caused many disasters.

4. Permissible electric miners' lamps for illumination and magnetically locked flame safety lamps for testing to prevent ignition of gas or bituminous coal dust by open lights or by safety lamps that can and may be opened underground.

5. Permissible electric coal-cutting drills, loading machines, switches, and cables installed and used in an approved manner, to prevent ignition of gas or bituminous coal dust by short circuits.

6. Permissible pumps, hoists, compressors, and other stationary machinery and devices permissibly placed and installed, to prevent ignition of gas.

7. Approved methods of placing and installing electric power lines, to prevent ignition of gas or bituminous coal dust.

8. Limitation of use of trolley locomotives to pure air intakes, outby an open crosscut, and to thoroughly rock-dusted haulage roads, with the object of preventing the ignition of gas or bituminous coal dust. The alternative, which is far preferable, is to use permissible storage-battery locomotives for haulage in all gassy or slightly gassy mines.

VENTILATION

CONSTITUENTS OF MINE AIR

Mine air differs from normal atmospheric air only in the extent to which it is contaminated by mine gases or its normal content of oxygen is depleted, as through absorption by the mine walls and by the coal.

Analysis of pure, dry, normal atmospheric air

	By volume	By weight
Oxygen (O_2)	20.93	23.024
Carbon dioxide (CO_2)	.03	.040
Nitrogen (N_2) [1]	78.10	75.499
Argon (A)	.94	1.437

[1] Includes small amount of rare gases like argon, comparatively inert to ordinary chemical reactions.

HUMIDITY

More or less aqueous vapor is always present in the atmosphere. The percentage of saturation, known as relative humidity, is rarely less than 30 per cent except in desert or arid districts; it usually ranges from 30 to 80 per cent, rising to 100 per cent, or the "dew point," when there is a fog and drops of visible moisture form.

Psychrometric tables, the determinations in which are regarded as standard, are published by the United States Weather Bureau (Bull. 35). Tables and charts devised from these tables, with special reference to mine ventilation, are given in Bulletin 20, Bureau of Mines,[1] and also in Peele's Mining Engineers' Handbook,[2] which gives data and shows a Bureau of Mines psychrometer.

The relative humidity of the air in most coal mines is high, for the ventilating current picks up moisture from the walls and the coal dust. When the outside air is colder than the mine air, as in winter, the entering air is rapidly warmed to the "ground" temperature; consequently its relative humidity is low until moisture is absorbed from the mine passages. Thus, during cold weather the effect of the ventilating current is to dry the mine and the mine dust.

NEED OF VENTILATION

Ventilation of coal mines is now so generally accepted as necessary that the time when definite artificial coursing of the air through a coal mine to dilute and carry away inflammable or noxious gases was unknown is forgotten. Systematic ventilation of metal mines is recent; inflammable gases are rare in metal mines, and hence the need of ventilation is not so obvious. When the Bureau of Mines began its studies of ventilation in metal mines in 1912, most of the metal mines in the United States relied upon haphazard natural ventilation, assisted by the compressed air used in jets and in drills. Now, some large deep metal mines have ventilating systems as complete as those in coal mines.

Many decades ago, when coal-mine workings began to extend some distance from the shaft or mine mouth, it was discovered that positive circulation of the air was vital, not only to carry away inflammable gases but also to supply the miners with breathable air to replace that vitiated by gases from the strata, by the flames of lamps, by the exhalation of men and draft animals, and by explosives.

COAL-MINE GASES CLASSIFIED BY ORIGIN

The individual gases found in coal mines, other than those in the pure air that is forced in or enters by natural ventilation, may include methane (CH_4), natural gas, carbon dioxide (CO_2), carbon monoxide (CO), nitrogen (N_2), sulphur dioxide (SO_2), sulphide of hydrogen (H_2S), oxides of nitrogen, and others. They may be classed as follows:

1. Gases entering from the strata (methane and, rarely, natural gas leaking from deep wells, nitrogen, and carbon dioxide).

[1] Rice, G. S., The Explosibility of Coal Dust: Bull. 20, Bureau of Mines, 1911, pp. 58–69.

[2] Peele, Robert, Mining Engineers' Handbook: 1st ed., New York, 1918. Sec. 28, by G. S. Rice, pp. 1384–1397. 2d ed., New York, 1927. Sec. 23, by G. S. Rice, pp. 1556–1558.

2. Gases produced by blasts of explosives and by mine fires and explosions (chiefly carbon dioxide, carbon monoxide, nitrogen, nitrous oxides from explosives that burn instead of detonating, hydrogen sulphide, sulphur dioxide, and various hydrocarbons).

3. Gases resulting from absorption of oxygen from the air and from slow oxidation of coal, carbonaceous matter, pyrite, and timber (carbon dioxide and residual nitrogen).

4. Gases exhaled in the breath of men and animals and given off by flame lamps (chiefly carbon dioxide and residual nitrogen).

5. Gases from internal-combustion engines driving pumps, hoists, and locomotives[3] (large amounts of carbon dioxide and carbon monoxide and residual nitrogen). The danger of miners being poisoned by carbon monoxide gas and the fire and explosion hazards that attend the use of gasoline underground are so grave that the Bureau of Mines can not recommend the use of internal-combustion engines in mines. Most State coal-mining regulations restrict or forbid their use.

6. Gases from explosions of gas and dust or from fires (complex changing mixtures in which the chief toxic or deleterious gases are carbon monoxide, carbon dioxide, various hydrocarbons, and residual nitrogen).

7. Gases from old disused and unventilated workings (possibly methane, carbon dioxide, excess nitrogen, and rarely in wet workings hydrogen sulphide and sulphur dioxide derived from the decomposition of sulphide minerals).[4]

Deficiency of oxygen in mine air is a serious matter in those mines where the coal absorbs oxygen rapidly; good ventilation at the faces is required to prevent deficiency of oxygen.

PHYSIOLOGICAL EFFECTS OF MINE GASES

Methane and nitrogen are physiologically inert.

Carbon dioxide may be an important constituent of so-called "black damp," which, according to the terminology of J. S. Haldane, is a mixture of carbon dioxide and nitrogen in various proportions. Sayers[5] states:

> Although carbon dioxide in itself is not poisonous, sometimes there is enough of it in mines to cause headache, sweating, dim sight, and trembling, and even unconsciousness and death. When 0.5 per cent carbon dioxide in the air is breathed, it causes a man to breathe deeper and a little faster, but no more so than when he moves about, and a little more carbon dioxide is formed in

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[3] Hood, O. P., and Kudlich, R. H., Gasoline Mine Locomotives in Relation to Safety and Health: Bull. 74, Bureau of Mines, 1915, 83 pp.

[4] Sayers, R. R., Sanitation in Mines: Miners' Circ. 28, Bureau of Mines, 1924, 16 pp.

[5] Sayers, R. R., Work cited, p. 11.

his muscles; with 2 per cent present a man will breathe about 50 per cent more air; with 3 per cent present he will breathe about twice as much air; with 5 per cent about three times as much; and when 10 per cent carbon dioxide is in the air a man can breathe the air for only a very short time.

Carbon monoxide is the most common toxic gas. The numerous deaths caused by the exhaust of automobiles in closed garages and by illuminating gas have acquainted the public with its deadliness. In mines carbon monoxide other than that from explosions or fires is produced by blasting. The gases produced by blasting are easily removed by systematic ventilation.

Of the physiological effects of carbon monoxide Sayers[6] remarks:

Carbon monoxide exerts its extremely dangerous action on the body by displacing the oxygen from combination with haemoglobin. Haemoglobin, the coloring matter of the blood, normally absorbs oxygen from the air and delivers it to the tissues through the blood. The affinity of carbon monoxide for haemoglobin is about 300 times that of oxygen. Because of this, even when only a small amount of the poisonous gas is present in the air breathed into the lungs, much of the haemoglobin is locked up in combination with carbon monoxide and so can not keep up its usual work of carrying oxygen to the tissues. These, because of the lack of oxygen, can not do their work properly. If they are smothered long enough, the tissue cells become damaged, and the injury to the cells may be permanent even if the patient survives. It has been asserted that carbon monoxide has a specific poisonous action on some tissues of the body, especially those of the nervous system, but there is little evidence in favor of this statement and much against it.

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With increasing concentrations of carbon monoxide, the time required for a given amount of haemoglobin to combine with carbon monoxide would decrease very rapidly, until with 1 per cent it may require only time enough to take a few breaths to produce a saturation of 60 to 80 per cent, which is fatal. Roughly, for a person at rest, it can be assumed that 80 per cent of the equilibrium values is attained after the following periods of time:

Concentration of carbon monoxide in air (inclusive)	Percentage blood saturation (80 per cent of approximate equilibrium values)	Time	Concentration of carbon monoxide in air (inclusive)	Percentage blood saturation (80 per cent of approximate equilibrium values)	Time
0.02–0.03	23–30	5 to 6 hours.	0.16–0.20	61–64	1 to 1½ hours.
.04– .06	36–44	4 to 5 hours.	.20– .30	64–68	30 to 45 minutes.
.07– .10	47–53	3 to 4 hours.	.30– .50	68–73	20 to 30 minutes.
.11– .15	55–60	1½ to 3 hours.	.50–1.00	73–76	2 to 15 minutes.

[6] Sayers, R. R., "Permissible limits of toxic and noxious gases in mine and tunnel ventilation": Paper before Am. Inst. Min. and Met. Eng., February, 1926, 14 pp.

Percentage of blood saturation	Symptoms
0 to 10	No symptoms.
10 to 20	Tightness across forehead; possibly slight headache; dilation of cutaneous blood vessels.
20 to 30	Headache; throbbing in temples.
30 to 40	Severe headache, weakness, dizziness, dimness of vision, nausea and vomiting, collapse.
40 to 50	Same as previous item, with more possibility of collapse and syncope, increased respiration and pulse.
50 to 60	Syncope, increased respiration and pulse; coma with intermittent convulsions; Cheyne-Stokes's respiration.
60 to 70	Coma with intermittent convulsions, depressed heart action and respiration; possibly death.
70 to 80	Weak pulse and slowed respiration; respiratory failure and death.

Sulphur dioxide is extremely irritating to the eyes and respiratory passages, 1 part in 500 being almost intolerable to breathe. Occasionally the proportion in a mine atmosphere is high enough to be dangerous. The gas is easily recognized by its characteristic odor and by the choking it causes when inhaled.

Hydrogen sulphide has a repulsive odor and even in low concentrations is extremely poisonous. The low limit of toxicity has not been determined but is less than 0.005 per cent. Sayers says that 0.06 to 0.1 per cent is enough to cause serious symptoms in a few minutes.

Oxides of nitrogen which sometimes, though rarely, are found after high explosives have burned instead of detonating are highly dangerous. Their effects on the respiratory passages are not usually manifest until several hours after exposure, when oedema and swelling begin. Sayers says that this irritation may be followed by bronchitis or pneumonia.

Inflammability limits of mine and other gases by percentage of air mixture

	Lower limit	Higher limit		Lower limit	Higher limit
Methane	[1] 5-5.4	15	Carbon monoxide	12.5	74
Hydrogen	4.1	74	Acetylene gas	2.5	73
Ethane	3.4	12.45	Gasoline vapor, approximate	1.5	6
Natural gas, approximate	[2] 2-5	13.46			

[1] Limit with turbulence of mixture, such as caused by a shot.
[2] Natural gas varies in composition; the limits given are those for gas piped to the experimental mine.

The foregoing determinations were made chiefly by G. A. Burrell and A. W. Gauger[7] but for several gases are modified by later determinations of British and American investigators.[8]

[7] Burrell, G. A., and Gauger, A. W., Limits of Complete Inflammability of Mixtures of Mine Gases and of Industrial Gases with Air: Tech. Paper 150, Bureau of Mines, 1917, 13 pp.

[8] Coward, H. F., and Jones, G. W., The Explosibility of Methane and Natural Gas: Carnegie Inst. Technol. Bull. 30, 1925.

TESTING THE QUALITY OF MINE AIR

The original method of testing the quality of coal-mine air was by an open flame, obviously a dangerous procedure if fire damp (methane) were present. When Davy invented the safety lamp in 1815, he provided a relatively safe method of testing with flame in quiet atmospheres. Methane in air lengthens the flame, whereas black damp, a mixture of carbon dioxide and more nitrogen than is normally present in pure air, shortens and dulls it. Where methane (CH_4) and black damp are found together, as they often are in the afterdamp or fumes (more or less diluted with air) from fires and explosions, the opposing effects make it impossible to judge by the appearance of the flame the proportions of the gases present. Then it is necessary to sample and analyze the mixture of gases to determine the proportions exactly.

As coal mines became deeper and increasing amounts of methane were encountered, stronger ventilating currents were necessary. Then it was found that the Davy lamp was not safe in these stronger currents, for the flame penetrated the gauze; moreover, the illuminating power of the Davy lamp was very small. These defects of the Davy led to the gradual development of flame safety lamps which culminated in the modern permissible flame safety lamp.

Other methods of testing the quality of the air and the presence of various gases have been developed in recent years. These have been grouped according to the respective gases as follows:

APPROVED INSTRUMENTS AND APPARATUS FOR DETERMINING PRINCIPAL MINE GASES

Methane (CH_4)

Portable instruments and devices:

1. Flame safety lamp (permissible).
2. Burrell gas detector (permissible).
3. Electrical detecting devices of various kinds.
4. Absorption and diffusion devices.

Stationary and laboratory apparatus:

1. Absorption and electrical apparatus, which may be continuously recording
2. Analytical laboratory apparatus.
   - (*a*) Orsat type.
   - (*b*) Haldane type.
   - (*c*) Fractional distillation at low temperature.

Carbon monoxide (CO)

Portable means and devices:

1. Canaries and mice.
2. Pyrotannic acid color device.
3. Iodine pentoxide color device.
4. Palladium chloride.

Stationary means and apparatus:

1. Catalytic and combustion recording apparatus.
2. Pyrotannic apparatus.
3. Analytical laboratory apparatus.
    (*a*) Haldane apparatus.
    (*b*) Iodine pentoxide.
    (*c*) Fractional distillation at low temperatures.

Carbon dioxide (CO_2)

Portable apparatus and means:

1. Flame safety lamps (in the absence of more than 1 per cent of methane).
2. Effect on breathing.
3. Orsat portable apparatus.

Stationary or laboratory apparatus:

1. Continuous recorder based on chemical reaction (for amounts over 1 or 2 per cent).
2. Analytical apparatus.
    (*a*) Orsat type.
    (*b*) Haldane type.

Oxygen (O_2)

Portable means and devices:

1. Effect on safety lamp (if methane is not present in amounts exceeding 1 per cent). Flame grows duller until it is extinguished when the oxygen falls to 17 per cent.
2. Effect on breathing as oxygen content falls and CO_2 is increased. If a man enters quickly an atmosphere containing only 5 or 6 per cent of oxygen he will probably drop unconscious.
3. Haldane wax taper and graduated glass tube.
4. Orsat portable apparatus.

Stationary or laboratory apparatus:

1. Analytical apparatus.
    (*a*) Orsat type.
    (*b*) Haldane type.

Nitrogen (N_2)

No portable devices. As nitrogen is inert to ordinary chemical reaction, it usually is determined by analytical "difference." It can be determined precisely by fractional distillation at low temperature.

Sulphur dioxide (SO_2)

A toxic gas rarely found in coal mines and only as a minor component of gases from blasting and from mine fires. It gives warning by its acrid smell when only 2 parts of it are present in a million parts of air; 1 part in 100,000 parts of air will cause choking; and 1 part in 1,000 will cause death if breathed for a short time. For determining SO_2 in air the methods of analysis most commonly used involve aspiration of measured volumes of air through absorption bottles containing solutions of caustic alkali, alkaline carbonates or bicarbonates, or iodine.[9]

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[9] Holmes, J. A., Franklin, E. C., and Gould, R. A., Report of the Selby Smelter Commission: Bull. 98, Bureau of Mines, 1915, p. 198.

Hydrogen sulphide (H_2S)

Hydrogen sulphide, a highly poisonous gas, is rarely found in mine atmospheres, although it sometimes is present in flooded workings that are being pumped out. In minute amounts it is detectable by its odor—that of rotten eggs; in larger and dangerous amounts it may not be smelled. Quantitative tests for its presence can be made only by an expert chemist. A recommended qualitative method employs ammonical cadmium chloride solution. The sample of gas is bubbled through the solution and the resulting cadmium sulphide is precipitated (Yant).

DETAILED DESCRIPTION OF PRINCIPAL METHODS AND INSTRUMENTS FOR TESTING THE PRESENCE AND DETERMINING THE PROPORTIONS OF GASES IN MINE AIR

Permissible flame safety lamps.—In this handbook it is not possible to describe in detail permissible flame safety lamps. The reader is referred to Bulletin 227, Bureau of Mines,[10] which gives details and describes use.

Although the requirements for permissibility of flame safety lamps are known to many mining men, it has been found that a great many do not appreciate certain vital features. Davy lamps are still used for testing in some mines in the United States, mostly in the anthracite district, where the old miners like them because they are small enough to carry in the pocket. Their use is highly dangerous in a gassy mine with a strong current of air.

Many mining men do not realize the importance of having a magnetically locked lamp which can not be opened underground. Fire bosses who should know better use modern flame safety lamps, but those that are key locked or without locks so they can open them in the mine. The flame safety lamp is not considered permissible by the bureau unless it is magnetically locked so it can not be opened underground.

Flame safety lamps too often are not properly cared for—the gauze is not kept clean, punctured gauze is not removed, and gaskets are not kept free from defect. Safety lamps when not in use should always be kept in a well-built lamp house near the mine mouth or man shaft, under the charge of a responsible, experienced lamp man who issues them only after careful testing. Some companies adopt the excellent plan of having a gas testing box for trying each lamp before it is issued.

Testing for methane with flame safety lamp.—Testing for methane with a flame safety lamp should invariably be done with the wick turned so low that the yellow part of the flame is cut out, leaving only the small deep-blue flame of the oil or gasoline used in the lamp. When a suitable grade of gasoline is used this flame should have a fuel cap not more than one-tenth inch high above the wick. If

[10] Paul, J. W., Ilsley, L. C., and Gleim, E. J., Flame Safety Lamps: Bull. 227, Bureau of Mines, 1924, 212 pp.

methane is present in the air, a conical cap of pale blue flame forms over the fuel flame. Time should be allowed for it to form. The height of the cap above the fuel flame indicates the percentage of methane in the air.[10a]

A too common practice of old mining men is to test with a full luminous flame and to try to judge from the spiring of the flame the amount of gas present. By such methods, especially if hasty, a dangerous percentage of gas—2 or 3 or even 3½ per cent—may escape undetected. On the other hand, if the flame is drawn down as described, an expert can easily detect 1 per cent and with great care as little as ¾ per cent. In estimating the volume of methane that may extend along the roof, the observer should bear in mind, if the lamp is of the Wolf type, that the mixture of gas and air enters the air-feed ring about 9 inches below the top of the lamp. Therefore, if he does not find gas on first testing where there is no air current, he should gently fan down air or gas from the level of the roof with his hands.[10b]

Fire bosses or examiners in most States are required to be certified. If they are not given a practical examination by the State officials, a mining company before appointing them to act as examiners (a responsible position) should have them undergo tests to see if they can determine within practical limits the percentages of gas in prearranged mixtures in a testing box.

Fire-damp detectors or indicators.—For many years inventors have tried to develop fire-damp detectors or indicators to replace the flame safety lamp; their aim has been to produce a device that would give more positive warning to miners, especially those who are inexperienced or careless, than is given by the flame of a safety lamp, and also to eliminate the hazards connected with the use of a flame lamp.

As used by the Bureau of Mines, a "gas detector" means a device that detects gas exceeding a certain limit or percentage in an air

[10a] In view of the varying quality of gasoline on the market and changes in the fuel cap with the temperature of the lamp, anyone testing for the presence of gas should from time to time during the shift test his lamp in pure intake air to determine the height of the fuel cap.

[10b] Bulletin 227, Bureau of Mines (see footnote 10), reports results of tests with various types of flame safety lamps on pages 182 to 197 and shows colored diagrams of the heights of the flame. An example of the heights determined with a permissible flat-wick lamp in different percentages of natural gas containing 82 per cent of methane, 16.4 per cent of ethane, and 1.5 per cent of nitrogen follows:

Gas, per cent	Height of flame, inches	Gas, per cent	Height of flame, inches
1	0.2	2½	0.55
1½	.4	3	.90
2	.45	3½	1.70

For higher percentages the top of the gas cap is indeterminate.

mixture. The term "gas indicator" is applied by the bureau to those instruments or devices which show or "indicate" precisely definite proportions of gas in air within certain tolerances for the determination errors. In other words, the detector is qualitative by showing merely the presence of gas exceeding a certain minimum, and the indicator is quantitative in its findings by showing the percentage of gas in air up to the explosive point.

A. *Methane detectors or indicators based on normal physical properties*

1. Density differences.
2. Acoustic properties (exemplified in the Harber whistle and Fleissner singing lamp).
3. Diffusion (osmosis) rate as through a porous diaphragm.
4. Optical or refractive index.

B. *Indicators based on low-temperature heat effects*

5. Heat rise produced by contact with a catalytic agent like platinum black.
6. Thermal conductivity when methane or methane and air mixtures are heated, usually by electric wire of a temperature below the igniting point of methane.

C. *Indicators based on electrical resistance or establishing circuits*

7. Change in electrical resistance of wires heated electrically in the presence of methane in air.
8. Change in electrical resistance when wires are heated by a small flame, as in a modified safety lamp.
9. Change of brilliancy of especially prepared or surface-treated wires heated electrically in mixtures of CH_4.
10. Establishment of electrical contact through heating of elements by a small flame, increased by the presence of CH_4, causing danger signals to be sounded or electric signal lamps to be lighted.

D. *Indicators depending on chemical reaction*

11. Change in gas volume or pressure, due to combustion in a protective vessel.

Descriptions of some of the detectors and indicators included in the foregoing classification are contained in Bureau of Mines Bulletin 227.[11] Descriptions of others appear in the Mining Engineers' Handbook.[12] An excellent review is given in a paper by McLuckie.[13]

At present (1927) the only detector or indicator, other than certain flame safety lamps (including the Wolf small-flame detector lamp), that has been placed on the permissibility list of the bureau is the Burrell indicator, which comes under class D. It is virtually a small

[11] Paul, J. W., Ilsley, L. C., and Gleim, E. J., Flame Safety Lamps: Bull. 227, Bureau of Mines, 1924, 212 pp.

[12] Peele, Robert, Mining Engineers' Handbook: 1st ed., New York, 1918, pp. 1416–1420. 2d ed, New York, 1927, pp. 1589–1594.

[13] McLuckie, Colin, "Fire-damp detector": Coll. Guard., Apr. 29, 1927, pp. 993–994.

volumetric analysis apparatus about the size and form of a flame safety lamp. It is accurate to within two-tenths of 1 per cent of methane, where there is less than 4 per cent of methane in the air.

SAMPLING AND ANALYSIS

The most accurate way of determining the constituents of a mine atmosphere is to take samples of it in vacuum tubes or by the displacement of water or air in special containers or ordinary bottles. The principal constituents of the samples are determined by gas analysis, either on the surface or in some underground station.[14]

Portable methane detectors and indicators.—Many portable methane detectors and indicators have been designed and, to some extent, tested experimentally during recent years. The functioning of many designs depended on changes in the electrical resistance of heated elements, such as platinum wire, at high temperatures. Other designs used catalytic agents, such as platinum and palladium surfaces, at relatively low temperatures intended to be below the ignition temperatures of methane in air. Most of the devices, including attachments to miners' storage-battery lamps, are designed to be of the portable type. In Great Britain and Germany prizes have been offered at different times for the development of detectors and indicators. Some look very promising, but as yet none have been approved by the Bureau of Mines. The advantage of a reliable, easily read, portable detector, especially one that gives a warning which can not be easily overlooked by the miner in his work, is obvious.

Stationary recording methane indicators.—Stationary continuously recording methane indicators which are accurate to within two-tenths of 1 per cent in air and could be safely placed in returns of splits or the main ventilation return of the mine would be of the greatest value in gassy mines in giving warnings of an inflow of fire damp, and in connection with an automatic continuous recorder of the volume of the air current, of the stoppage or checking of the ventilating current, or, on the other hand, of the short circuiting of the air. Such indicators are now being developed by certain manufacturers with promise of success.

Methods of detecting carbon monoxide in blood and in air.—Sayers[15] states that a number of methods have been devised for the detection and determination of carbon monoxide in the blood and in the air, such as Hoppe-Seyler's caustic soda solution reaction, Salkowski's

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[14] Burrell, G. A., Seibert, F. M., and Jones, G. W., Sampling and Examination of Mine Gases and Natural Gas: Bull. 197, Bureau of Mines, 1926, 108 pp. Fieldner, A. C., Jones, G. W., and Holbrook, W. F., The Bureau of Mines Orsat Apparatus for Gas Analysis: Tech. Paper 320, Bureau of Mines, 1925, 18 pp.

[15] Sayers, R. R., and Davenport, Sara J., Carbon Monoxide Literature: Public Health Bull. 150, April, 1925, p. 26.

hydrogen sulphide test, Zaleski's copper sulphate test, Kunkel and Wetzel's tannic acid and potassium ferrocyanide test, Ruber's lead acetate test, and the tests of Katyama, Landois, Schulz, and others, all based on the general rule that carbon monoxide haemoglobin retains its red color, especially in the presence of many chemical precipitants, whereas normal blood changes to a grayish green to brown.

The spectrophotometric method was adapted and developed by W. P. Yant, of the Bureau of Mines, for use in work on carbon monoxide. The method is based on the fact that haemoglobin in combination with carbon monoxide has the power of absorbing light of wave lengths different from those absorbed by haemoglobin in combination with oxygen; and that any mixture of the two combinations will show a proportionate amount of that difference, corresponding to the percentage of each in the mixture. Results can be had with this method in a few minutes, but the apparatus required is costly and can be used only by careful, experienced analysts.

In 1912 Haldane published a description of his colorimetric method for determining the percentage of saturation of haemoglobin with carbon monoxide. He found that with proper precautions this method would give very accurate results. However, other investigators have reported that the method gives fair accuracy when the concentrations of carbon monoxide in the blood are comparatively high, but is inaccurate when they are low, at best is tedious, and is satisfactory only when used by careful analysts and those who have a very keen eye for color.

The pyrotannic acid method of Sayers and Yant [16] gives accurate results, can be used by a person without special training, and is suitable for both field and laboratory studies. This method is based on the fact that a light-gray suspension forms a few minutes after normal blood diluted with water is treated with a solution of tannic and pyrogallic acids, whereas a light-carmine suspension is formed from blood having carbon monoxide in combination with the haemoglobin. Moreover, in any mixture of normal blood and blood containing carbon monoxide the resulting suspension will be a corresponding blend of the two extremes of color. The apparatus consists of a set of standards to represent the different colors of varying but known amounts of carbon monoxide in combination with haemoglobin. Unknown specimens can be matched with these standards, and the proportion of carbon monoxide haemoglobin evaluated. By this method the percentage saturation of haemoglobin with carbon monoxide in the blood can be easily determined within 5 per cent.

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[16] Sayers, R. R., and Yant, W. P., The Pyrotannic Acid Method for the Quantitative Determination of Carbon Monoxide in Blood and in Air: Tech. Paper 373, Bureau of Mines, 1925, 18 pp.

The pyrotannic acid method described above can also be used satisfactorily for the quantitative determination of carbon monoxide in air by adding to the apparatus air-sample bottles (capacity at least 250 c. c.) fitted with rubber stoppers and a rubber aspirator bulb with a scrubber (a tube of soda lime) attached for removing gases that might have an interfering effect. Determination of the amount of haemoglobin combining with either carbon monoxide or oxygen and a knowledge of the partial pressure of one of them permit calculation of the partial pressure of the other. The actual error of this method for determining carbon monoxide in air, even when used by inexperienced men, was found to be 0.005 in regions of 0.000 to 0.05 per cent, 0.01 in regions of 0.05 to 0.08 per cent, 0.02 in regions of 0.08 to 0.12 per cent, and 0.03 in regions of 0.12 to 0.18 per cent of carbon monoxide. In connection with the tunnel-gas investigations, the determination of carbon monoxide in air was developed by M. C. Teague to a point where an experienced operator could determine as low as 2 parts in 100,000 parts of air.

Other methods of determining carbon monoxide.—*Small animals.*—Small animals, such as birds and mice, have been used for years in mine rescue work in this country and abroad. Technical publications and textbooks frequently mention their practical use in explorations after mine disasters. Their especial value is to indicate to a rescue party with a given supply of breathing apparatus and accessories when such apparatus needs to be used. In 1914 the Bureau of Mines published the results of tests [17] to determine the relative sensitiveness of small animals to repeated exposures to atmospheres containing carbon monoxide (a fact not previouly determined by actual experiments) and the relative fitness of different kinds of small animals for use in exploring mines. Birds, especially canaries, proved most suitable because they show symptoms of distress earlier and are easier to observe. In general, canaries showed signs of distress when exposed for 60 minutes to 0.1 per cent, for 5 to 30 minutes to 0.15 per cent, and for 2 to 5 minutes to 0.2 per cent of carbon monoxide. Mice proved slightly more resistant.

Iodine pentoxide indicator.—One product of the activities of the United States Chemical Warfare Service was a simple device and method for rapid determination of small quantities of carbon monoxide in air. Since the war this device, known as the "hoolamite" or activated iodine pentoxide indicator, has been applied to commercial uses. Hoolamite is prepared by mixing fuming sulphuric acid with iodine pentoxide and using granular pumice stone as a supporting material. A sample of the air to be tested is drawn into a small

[17] Burrell, G. A., and Seibert, F. M., Relative Effects of Carbon Monoxide on Small Animals: Tech. Paper 62, Bureau of Mines, 1914, 23 pp.

rubber bulb, then forced through a small glass tube filled with hoolamite. Carbon monoxide changes the hoolamite from its original gray or white to shades of green; the deepness of the green is determined by the proportion of carbon monoxide in the air. A color scale attached permits determination of percentage. The determination may be made in a few minutes.

The Bureau of Mines tested this detector for use in mines and found that it had a material advantage over animals. Although canaries and mice quickly give warning when the percentage of carbon monoxide is around 0.2, they do not help much in atmospheres containing around 0.1 per cent, whereas the detector gives warning when the percentage is less than 0.1. In fact, in this type of detector the color scale used for comparison covers the range from 0.05 to 1 per cent. Another advantage the detector has as compared with canaries or mice is that it can be carried by persons wearing oxygen breathing apparatus through atmospheres containing as much as 1 per cent of carbon monoxide to points farther on and will accurately show the proportion of carbon dioxide there, whereas a mouse or canary carried through a similar atmosphere would be dead when the party reached the more distant points. However, Doctor Haldane, the noted British physiologist, designed a tight, portable glass and metal cage fed by oxygen to meet such an emergency and also to revive a canary or other animal when overcome, but it has not been generally accepted for mine rescue work.

Carbon monoxide recorder.—As an outgrowth of studies by the Bureau of Mines for the Holland vehicular tunnels under the Hudson River between New York and New Jersey, an apparatus[18] was developed that continuously analyzes and records very low concentrations of carbon monoxide in air. The principle employed is selective combustion of the carbon monoxide in the presence of a catalytic material in which the temperature rise is measured by differential multiple thermocouples connected with a potentiometer recorder. A recorder having a cell of 48 couples has given continuous and satisfactory service. It records on a time chart the CO in parts per 10,000 and fractions thereof and is sensitive to about 0.02 per 10,000 (2 parts per million). The range of this apparatus is from none to 9 parts of CO per 10,000 of air. A warning bell is arranged to ring when the CO reaches a concentration of 4 parts per 10,000 or more. If desired the bell-ringing system can be designed to operate a relay switch to increase ventilation automatically by speeding up the fan motors.

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[18] Katz, S. H., Reynolds, D. A., Frevert, H. W., and Bloomfield, J. J., A Carbon Monoxide Recorder and Alarm: Tech. Paper 355, Bureau of Mines, 34 pp.

ANALYTICAL APPARATUS[19]

For the analysis of mine air and mine gases the Bureau of Mines uses two types of apparatus—the modified Orsat and the modified Haldane.

Modified Orsat apparatus.—All samples of mine air that contain enough combustible gases to render them inflammable or enough oxygen to supply these combustible gases with oxygen during the procedure used are analyzed by the Bureau of Mines modification of the Orsat apparatus. The constituents determinable by this type of apparatus are carbon dioxide, oxygen, unsaturated hydrocarbons, hydrogen, carbon monoxide, methane, ethane, and nitrogen, but the analytical procedure may be modified to include part or all of these, as desired. The limit of accuracy is approximately 0.2 per cent by volume. The time required for an analysis depends on the constituents to be determined, but all of the entire group given may be determined in approximately one hour.

For mine-fire control and for recovery operations after fires and explosions the bureau uses a portable water Orsat apparatus, which is somewhat less accurate than the laboratory type, but is accurate enough to determine the dangers from mixtures of inflammable gas and the effect of changes in conditions, especially with respect to the percentage of oxygen present.

Modified Haldane apparatus.—The Bureau of Mines modification of the Haldane type of apparatus is used for analyzing all mine-air samples that do not contain an inflammable concentration of combustible gases but do contain enough oxygen to permit combustion of these gases in the analytical procedure and at least 70 to 75 per cent of inert gas (N_2). The constituents that may be determined by the Haldane apparatus are carbon dioxide, oxygen, methane, carbon monoxide, hydrogen, and nitrogen, and the procedure may be modified to include all or part of this group. The limit of accuracy is approximately 0.02 per cent by volume. The time required for making an analysis depends somewhat on the constituents desired. A sample of normal mine air in which the proportions of carbon dioxide, oxygen, methane, and nitrogen are to be determined may be analyzed in 30 minutes. If contamination has been due to products of combustion of explosives, leaks from fire seals, or afterdamp, all of which may introduce carbon monoxide and hydrogen as additional contamination products, approximately one hour is required for a complete examination. When the amount of carbon monoxide approaches that of the analytical error the presence of this constituent

[19] Information supplied by A. C. Fieldner and W. P. Yant, of the Bureau of Mines.

is confirmed by the pyrotannic acid blood method, which will positively detect 0.01 per cent.[20]

ANALYSIS OF HYDROCARBON GASES BY FRACTIONAL DISTILLATION AT LOW TEMPERATURES AND PRESSURES

For the precise determination of the composition of mixtures of hydrocarbon gases—methane, ethane, propane, butane, etc.—as well as certain other gases, it is necessary to resort to the fractional distillation method that depends upon the difference in the boiling points of various liquefied gases.

The procedure is to liquefy the mixture by a surrounding bath of liquid air to the temperature of the latter, then by adjusting the temperatures successively to the different boiling points to draw off the desired gas. The method is slow and suited only for special laboratory research work.[21]

EFFECT OF INERT GASES ON INFLAMMABILITY LIMITS

The effect of inert gases on the inflammability limits of methane-air mixtures, a matter of importance in fighting mine fires, has been studied by several investigators. Clement,[22] by adding CO_2 to a methane-air mixture, found that the range of inflammability narrowed, the lower limit rising from 5.8 per cent with virtually normal air to 6.5 with 14 per cent of oxygen and the higher limit falling from 14.2 to 6. 9 with 14 per cent of oxygen. Burgess and Wheeler [23] obtained a slightly different range with these methods and apparatus, but, essentially, inflammability ceased when the oxygen content of the CO_2-methane-air mixture was 15.8 per cent. These investigators found that, if the inert gas added is nitrogen, inflammability ceased with 13 per cent of oxygen in the air. This limit is lower than that when carbon dioxide is present, mainly because nitrogen has a lower specific heat than carbon dioxide.

Different proportions of carbon dioxide and (excess) nitrogen in the methane-air mixtures would evidently cause corresponding changes in the limiting extinctive atmosphere when the contents of

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[20] Sayers, R. R., and Yant, W. P., The Pyrotannic Acid Method for the Quantitative Determination of CO in Blood and in Air: Tech. Paper 373, Bureau of Mines, 1925, 18 pp.

[21] Burrell, G. A., Seibert, F. M., and Robertson, I. W., Analysis of Natural Gas and Illuminating Gas by Fractional Distillation at Low Temperatures and Pressures: Tech. Paper 104, Bureau of Mines, 1915, 41 pp. Shepherd, Martin, and Porter, Frank, "An improved method for the separation of gas mixtures by fractional distillation at low temperatures and pressures": Ind. and Eng. Chem., vol. 15, November, 1923, p. 1143.

[22] Clement, J. K., The Influence of Inert Gases on Inflammable Gaseous Mixtures: Tech. Paper 43, Bureau of Mines, 1913, 24 pp. Coward, H. F., and Hartwell, F. J., The Limits of Inflammability of Fire Damp in Atmospheres Which Contain Black Damp: British Mines Dept., Safety in Mines Research Board Paper 19, 1926, pp. 5, 9, 10.

[23] Burgess, M. J., and Wheeler, R. V., The Limits of Inflammability of Fire Damp and Air: British Mines Dept., Safety in Mines Research Board Paper 15, 1925, 7 pp.

oxygen is between 13 and 15.8 per cent. Jones and Perrott [24] found that in hydrogen-air mixtures at about the upper limit of inflammability—72 per cent—as little as 5.9 of oxygen would permit propagation of flame. At the lower limit of inflammability—40 per cent—it required 20.1 per cent of oxygen to permit propagation of flame.

On mixing carbon dioxide with the air and hydrogen when there was 6 per cent of hydrogen and 56.5 per cent of CO_2 in the mixture, only 7.8 per cent of oxygen was required to propagate flame.

In mixtures of carbon monoxide, air, and CO_2 at the upper limit of inflammability—72 per cent—only 5.9 per cent of oxygen was needed. At the lower limit, with 13.3 per cent of CO, 18.1 per cent of oxygen was needed; and with 16.5 per cent of CO, and 34 per cent of CO_2 only 10.3 per cent of oxygen was required to propagate flame.

The various mixtures of inflammable gases and extinctive gases cited above are not identical in composition with coal-mine fire gases behind seals. Mixtures of such gases, however, must differ widely in composition, especially if the sealed area gives off methane. The limits of explosibility of a range of synthetic mine-fire gas mixtures should be determined. It is proposed that this be done in the Bureau of Mines gas laboratory when opportunity arises.

The experiments so far made to test the effect of different inert gases in mixtures with inflammable gases and oxygen on the propagation of flame have shown that although there are differences in effect proportionate to the differences in specific heat of the respective inert gases, such differences are not great; and for practical purposes, as in mine-fire control, the ratio of the oxygen to the inflammable gases is the vital factor. The problem is to determine the ratios for a wide range of inflammable gas mixtures, as has been done for many individual gases.

AMOUNT OF AIR REQUIRED TO VENTILATE A COAL MINE

While working hard a man requires about 35 cubic feet of fresh air a minute. That amount, however, does not nearly meet a man's needs underground, as the gases given off in his working place must be swept away, and the oxygen absorbed by the coal and by oxidation of the timber must be replaced.

Every State coal-mining law but one calls for a minimum of 100 cubic feet a minute for each man and in gassy mines 150 to 200 cubic feet a minute (the latter figure is required by the anthracite regulations of Pennsylvania). Most State regulations, probably on the theory of limiting the number of men exposed to fumes

[24] Jones, G. W., and Perrott, G. St. J., "Oxygen required for the propagation of hydro-

from a fire, specify that not more than 70 or 75 men remain in one split of air current. A few States require less, but 75 seems to be a reasonable limit.[25]

Only a few laws specify where the measurement of the air currents shall be made. Generally they permit the volume of air entering the mine to be measured at the foot of the shaft or in the entrance of a slope or drift. Tests have shown that in 16 Illinois coal mines[26] only 7.6 to 33 per cent (or an average of 18.6 per cent) of the air leaving the fans reached the last crosscuts nearest the respective faces, because of leakage at doors and stoppings and through crevices in pillars and roof. This leakage represents a great waste of air and power. Good practice requires that at least 50 per cent of the air entering a mine shall reach the faces.

A better requirement than that calling for a minimum average volume of ventilation per underground employee, which may be measured at or near the entrance of the main intake, is to require a minimum volume for each and every man in his working place. If that is done, so far as the health of workers is concerned 75 to 100 cubic feet a minute for each man would be ample in the average nongassy or slightly gassy mine. In order that methane may be carried away, gassy mines may require a current of much larger volume than is needed to provide good air for breathing. Air in working places and used entries should contain not less than 20 per cent of oxygen, not over 0.25 per cent of carbon dioxide, and as little inflammable gas as possible.

Even in a mine that is rated gassy men should be withdrawn from a working place when 2 per cent of inflammable gas is diffused through the atmosphere there, although this percentage is below the lower limit of explosibility of methane in a mixture with air—5.2 per cent. Where 1 per cent of methane is found in moving air in any split, it is almost certain that somewhere along that split, at the face or in a roof cavity, a dangerously high percentage of inflammable gas will be found.

The best practice in gassy mines is to keep the gas content of every split below 0.5 per cent of methane by increasing the current of the split or reducing the area served by the split, which sometimes may require the subdivision of a split.

Bodies of gas should never be fanned out by men waving coats or brattice cloth, for that practice has caused many disasters. Gas should be removed by suitable coursing of the air, aided by line

[25] For detailed figures on minimum air requirements and maximum number of men on a split, see p. 138.

[26] Williams, R. Y., Mine Ventilation Stoppings with Especial Reference to Coal Mines in Illinois: Bull. 99, Bureau of Mines, 1915, p. 14.

brattices, when no man or source of ignition is on the return from that split. If the body of gas is large—say, 25 cubic feet of pure methane or 500 cubic feet of explosive mixture—no one except those necessary to manage the ventilation should be permitted in the mine until the proportion of gas is lowered to 1 per cent.

In some mines in Belgium, France, and certain districts of Canada the volume of gas given off is so great that violent outbursts occur; these necessitate special provisions, such as keeping boreholes ahead of all advance workings, testing the quantity and character of the gas given off, advancing the headings slowly to allow gas to drain off, not turning rooms until the area has been well drained, and blasting electrically when all persons are out of the mine. Such outbursts have been inconsequential and rare in mines of the United States, but they may occur at depth in regions where the coal beds are much faulted or folded.

GASSY OR NONGASSY[27] MINES

Precise definition of a gassy mine is of vital importance in coal mining. None of the State regulations specifically define a gassy mine, except to say that it is determined as such by official decision of the mining department of the State concerned. The Operating Regulations to Govern Coal-Mining Methods and the Safety and Welfare of Miners on Leased Lands on the Public Domain, formulated under the auspices of the Bureau of Mines in 1921, do give methods of determining a gassy mine. Recent developments in mining methods at the face and in electric installations and additional experience from explosion accidents make it seem necessary to lower the limits given in those regulations.

The bureau is frequently asked to specify what constitutes a gassy mine, and thus enable mine operators and State mining departments to formulate requirements for mine ventilation and regulations governing the installation and use of electric machinery and power lines. The bureau believes that all coal mines are potentially gassy but admits that there are wide differences in the proportion of inflammable gas found and hence in the degree of danger. Scott Turner, director, approved the following classification by the mine safety board of the Bureau of Mines on May 6, 1926, for policy and for teaching by the bureau's mining staff.

[27] Although the word "gaseous" has been widely used in this country, it is literally incorrect; hence the word "gassy" has been adopted by the Bureau of Mines for this bulletin and for future publications.

CLASSIFICATION OF COAL MINES BY GAS CONTENT

Class 1 coal mine.—A practically nongassy mine in which inflammable gas in excess of 0.05 per cent can not be found by systematic search.

Class 2 coal mine.—A slightly gassy mine in which (*a*) inflammable gas can be found,[28] but in amount less than 2 per cent, in still air in any active or unsealed abandoned workings; or (*b*) inflammable gas can be found,[28] but in amount less than 4 per cent, in some place from which the ventilating current has been shut off for a period of one hour; or (*c*) inflammable gas can be found,[29] but in amount less than 0.25 per cent, in a split[30] of the ventilating current; or (*d*) inflammable gas enters a split[30] of the ventilating current at a rate[31] not exceeding 25 cubic feet per minute.

Class 3 coal mine.—A gassy mine in which inflammable gas is found in amount greater than specified for a class 2 coal mine.

NOTES ON CLASSIFICATION OF MINES BY GAS CONTENT

With rare exceptions, the inflammable gas found in coal mines is methane. In coal-mining fields where deep wells that pass through the mines or through near-by ground reach natural gas in beds below the coal there have been rare instances of leakage of gas from a well. Natural gas almost always contains more than 85 per cent of methane, and usually ethane, propane, and traces of butane, and higher hydrocarbons as well; therefore the presence of these gases in mine air indicates leakage from a gas well. The lower limit of explosibility of methane-air mixtures in a state of turbulence is 5 per cent, and of natural gas-air mixtures with about 10 per cent of ethane and associated hydrocarbon gases is 4.6 per cent. The limit, therefore, varies with the character of mixture. Also the limit is lowest when ignition is at the bottom of the mixture and the mixture is in a state of turbulence, such as that caused by a blast.

To classify a coal mine properly it is advisable that systematic testing and sampling be done in the return of each split and in areas under suspicion at least three times in not less than 72 hours. All but one of the tests and samples of mine air must show less

[28] By employing an approved flame safety lamp, with flame drawn low, or by employing an approved gas detector, or by sampling and analysis with an approved gas analytical apparatus.

[29] By sampling and analysis with an approved gas analytical apparatus or by employing an approved gas detector.

[30] If but one continuous ventilating current is employed in a mine, this shall be considered a "split" for the purpose of this definition.

[31] Determined by sampling and analysis and measurement of the ventilating current.

inflammable gas than the maximum limit of the class to which the mine is assigned. In other words, a tolerance of one test or analysis may be permitted to provide for a mistake in sampling or analysis, or a very exceptional condition.

When a new mine is being opened in a coal field in which the existing mines make gas, it is common sense to assume that gas will be found in the new mine, and the development and equipment should be based upon the expectation that the mine will be assigned to class 3.

The old practice of classifying one part of a mine as gassy and another part as nongassy is considered to be dangerous where open lights are used and other nonpermissible devices and machinery are installed, for experience has shown that such equipment may at times be used in the gassy part of the mine.

MEASURING THE VOLUME OF MINE AIR

Every State code of regulations requires, by direct wording or by implication, periodic measurement of the volume of mine air by the mine foreman or an assistant. The place where the measurement is to be made is not the same in all codes; most of them merely require a specific number of cubic feet of air for each underground employee or draft animal. A few codes also specify that measurements be made in the last open crosscuts or break-throughs of each split of air. Most code requirements are satisfied with measuring the main intake or the main return, but the best practice is to make measurements weekly (in a gassy mine daily) of the main intake and the main return, and also of each split at the last crosscut or break-through traversed nearest the face workings of that split. In addition, it is advisable to measure the air entering each working place.

The volume of air is found by measuring the velocity with a sensitive standardized anemometer and multiplying the velocity by the cross-sectional area in square feet.

The United States Bureau of Standards, Washington, D. C., tests anemometers submitted to it and supplies a table of correction factors for different velocities. To get a fair average measurement of velocity, care should be taken to keep the anemometer away from the body, hold it at right angles to the direction of the air, and move it slowly zigzag across, up, and down the cross section. If the anemometer is held, as it sometimes is, centrally in the area or where the current is strongest, the reading is liable to be 50 per cent greater than the true average velocity.

Suitable places, which have smooth walls to avoid turbulence of the air, should be selected near the shafts or entrances, and the velocity of air in the main intake and the main return should always be measured in the same places for purpose of comparison; similarly, test places should be selected in each split.

The ordinary methods of determining the velocity of the main intakes and returns should be checked at least twice a year (during a nonworking shift) by dividing the cross section at the selected places into 2-foot (or smaller) squares with strings or wires, holding the anemometer in each square for a limit of time, and then averaging. It is still better to have these figures checked by pitot tube instruments in conjunction with the Ellison or the Wahlen gauge.

Interesting information that is of direct value for some purposes, such as physiological effects, is obtained by determining the relative humidity of the intake, the returns, and the air in the working places with a standardized wet and dry bulb instrument, either the sling psychrometer of the United States Weather Bureau or the whirling prime psychrometer designed by the Bureau of Mines.

For a discussion of the humidity of mine air and the determination of humidity see Bureau of Mines Bulletins 20 [32] and 197.[33]

METHODS OF VENTILATING COAL MINES

The earlier practice in coal-mine ventilation was to circulate one current of air around the whole mine. Furnaces were much used to induce a draft. Later, as the mines became larger, it became necessary to divide or split the current. Some State regulations now limit the number of men on any one split to 70. Fans supplanted furnaces and are now required by State laws, because underground furnaces may start mine fires or ignite gas.

ARRANGEMENTS FOR VENTILATION IN SHAFTS, SLOPES, OR DRIFTS

At least two entrances and exits for ventilation and for escape ways are now considered fundamental requisites for every coal mine. To have one of the entrances or exits through an adjoining mine is deemed permissible under certain restrictions. However, as frequent sad experience has shown, it is advisable wherever possible for every mine to have its own system of ventilation and escape ways—to be independent of adjacent mines and to be separated from those mines by substantial pillars, so that an explosion or fire in one mine will not jeopardize another.

Under special conditions—for example, where mines are old or extend deep under mountains—it is difficult to avoid interdependence of ventilation and escape ways, but such connections should be made with greatest regard to the safety of employees.

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[32] Rice, G. S., The Explosibility of Coal Dust: Bull. 20, Bureau of Mines, 1911, 204 pp. Williams, R. Y., Humidity of Coal Mine Air, Illinois: Bull. 83, Bureau of Mines, 1914, 69 pp.

[33] Burrell, G. A., and Seibert, F. M. (revised by Jones, G. W.), Sampling and Examination of Mine Gases and Natural Gas: Bull. 197, Bureau of Mines, 1926, pp. 7–11.

Such provisions are defined in the Operating Regulations to Govern Coal-Mining Methods and the Safety and Welfare of Miners on Leased Lands on the Public Domain. These provisions were formulated by the Bureau of Mines in cooperation with mine operators and State inspectors of the public-domain States and were published in 1921.[33a] For the most part they are consistent with the bureau's present recommendation. Excerpts from pages 7, 8, 10, 26, 35, and 36 follow:

Second exit to surface to be provided where more than 10 men employed on a shift.

SEC. 11. In every separate mine in which more than 10 men are employed underground on any shift the lessee shall provide in addition to the main shaft, slope, or drift, an escape way or second means of egress to the surface, which in case of drift, slope, or tunnel exits shall be separated at the surface from the first exit by not less than 50 feet of rock or coal in place; and if either or both exits are by vertical shaft or by inclined shaft, the exits shall be not less than 200 feet apart.

Outlet through adjoining mine.

An escape way or outlet through an adjoining mine which has adequate facilities for escape will be regarded as a satisfactory compliance with this requirement if at all times available and kept in proper condition for use. If such adjoining mine shall be abandoned at any time or shall cease to operate indefinitely, the lessee hereunder shall be solely responsible for the cost and expense of maintaining such outlet, and if such outlet shall be abandoned or permitted to become unsafe for use, not more than 10 men shall be employed underground in the mine on any one shift until a second exit or escape way is obtained and made safe for use: *Provided*, That where men have been entombed by an accident this regulation will be suspended for the purpose of carrying on rescue work.

Hoists and stairways and ladders required for egress in shafts in which more than 10 men are employed.

SEC. 12. In any shaft mine in which more than 10 men are employed underground on any shift, unless there is means of escape by drift, tunnel, or slope, one shaft must be equipped with hoist and cage suitable for hoisting or lowering men as specified in sections 21 to 25. The second shaft serving as an escape shaft may be provided with a substantial stairway with handrails, the flights not over 45° pitch with suitable landings at each turn.

Hoists required at both shafts when over 300 feet deep and more than 100 men are employed underground.

SEC. 13. In a mine in which more than 100 men are employed underground on any shift, if the escape shaft is more than 300 feet in depth vertically, it shall be provided with an adequate hoist and cage and a signaling system for hoisting men, and a qualified and experienced hoist man shall be available, on appropriate signal from underground of fire, explosion, inundation, or other emergency, to proceed to the hoist and act as hoist man. The hoisting equipment and cages in each of the two shafts—main shaft and escape shaft—shall have sufficient capacity independently of one another to hoist out of the mine all persons on any shift in 30 minutes, with due regard to safety in emergency hoisting.

[33a] The regulations were issued by the Secretary of the Interior. The immediate supervision of the operating regulations since July 1, 1925, has been in charge of the United States Geological Survey.

Emergency ladderway in shafts over 300 feet deep.

SEC. 14. In shaft mines over 300 feet in depth in which over 100 men are employed underground on any shift either in the main or escape shaft, there shall be an emergency ladderway with landings every 20 feet vertically apart and not exceeding 80° pitch. A stairway as described in section 12 may be substituted for the ladderway.

Passageway around shafts.

SEC. 15. At each landing of a shaft there shall be made and kept free of obstruction a passageway at least 6 feet high and 4 feet wide that will enable persons to pass from one side to the other side of the shaft without passing through any compartment of the shaft: *Provided*, A compartment of a shaft may be used for a passageway if same is not used for hoisting, when properly floored and roofed over by bulkhead sufficiently strong to protect men passing underneath from heavy falling bodies.

Main entries and airways over 4,000 feet from shaft.

SEC. 19. When any portion of the coal on the lease requires for its extraction main levels or entryways for ventilation and escapeways more than 4,000 feet in length beyond the nearest air shaft or place of egress, in which area may be comprised the workings in one or more separate coal beds of the same mine, and in which area more than 100 men are employed on any shift, the entries and airways extending to such section or area shall be not less than four in number: *Provided*, That where only two levels or entries are driven prior to entering such section or area, entry pillars shall be left of sufficient width to permit the driving of the necessary additional passageways to the area. Separated pairs of parallel entries entering the area in question and properly maintained will fulfill the foregoing respective requirements: *And further provided*, That if the advancing longwall method is used to extract the coal, pillars will not be required, but the number of levels or entryways specified shall be made and maintained in good order through the areas excavated by the longwall method: *And further provided*, That if coal on leased land is to be mined from a mine already existing either on the public domain or private ownership, and if, in the opinion of the mining supervisor, there are adequate ventilation passageways and escapeways, the foregoing requirements may be waived with the approval of the Secretary of the Interior.

Additional passageway.

Mines may be developed on leased tract through an adjoining mine.

SEC. 75 (a). A lessee may develop a mine on his leased tract from an adjoining mine not on the public domain or from adjacent leased lands, under the following conditions:

(b) If the mine not on the public domain conforms to all the sections in these regulations that relate to the safety of the mine and its employees;

(c) The only connections between the mines shall be the main haulage road, the ventilation entries, and the escape ways; that is to say, there shall be no unnecessary connections through the boundary barrier pillars between the mines. These barrier pillars shall not be extracted until both mines are about to be exhausted and abandoned unless with the consent of the mining supervisor;

(d) There shall be rock-dust barriers placed in the connecting passageways through the boundary barrier pillars in accordance with the preceding subsection 74h;

(e) Ample ventilation shall be maintained in both mines in accordance with previous sections.

Connections with adjacent mines, stopped up or if open, may be closed by emergency fire doors.

SEC. 104. (a) All connections with adjacent mines, if not used for haulage escapeway exits or airways, shall be sealed with stoppings which shall be fireproof and be built to withstand a pressure of 50 pounds per square inch on either side, calculated by a formula or method approved by the United States Bureau of Standards.

Fire doors in mine connections.

(b) There shall be installed in any open connections substantial iron or concrete fire doors, set in substantial fireproof frames, which may be closed in an emergency by authorized officials but which may be reopened from either side to permit the escape of men who may be trapped behind them in case of fire or explosions. Such doors shall be installed in duplicate, and the distance between doors shall be at least 40 feet.

In shaft mines that have only two shafts the best practice is to have the main hoisting shaft the downcast carrying the fresh air, and the air shaft the upcast carrying the return. The escapeway or stairway should be in a separate compartment of the downcast shaft, so that it will be in fresh air in the event of an explosion or fire. At some mines the intake and return have been placed in the same shaft but separated by a partition, an arrangement that is not considered good practice, for in an explosion the partition is very likely to be blown out of place, as happened at the Marianna mine (Pa.) explosion of 1908 and a number of other serious disasters. Moreover, if fire reaches the shaft it is likely to burn a wooden partition, and even if the partition is of concrete, fire at the bottom will render both compartments unavailable. In some large modern mines the hoisting shaft is neutral; that is, it is not used for a main intake or main return and is ventilated only by a small split of intake air; this arrangement is satisfactory and safe only if the split is positive.

For adequate fire protection and economic maintenance the shafts of long-lived mines should be lined with concrete or incombustible material throughout. It is better to have shafts circular or elliptical in cross section, the universal practice in deep European mines. Circular shafts have the advantage that ventilating currents are not materially checked by moving cages or skips, which in shafts of rectangular cross section have the effect of tight-fitting pistons where they pass each other.

More recently, in connection with the use of skips and underground dumping a new problem has arisen—that of dust accumulating on the buntons and the projecting frames of shaft linings. To prevent this accumulation and to lessen the friction of the air it is highly desirable that smooth linings be employed. Dangerous amounts of dust or loose material can be kept from collecting on buntons or crosspieces for the support of guides by installing these at longer intervals than usual and making them V shaped (inverted) on top to give sloping surfaces that offer no lodging place for coal dust.

VENTILATING SHAFTS OR COMPARTMENTS

Ventilating shafts or compartments should always be smooth lined. Tests made at Butte, Mont., in cooperation with the Bureau of Mines, demonstrated [33b] that smooth-lined shafts save a considerable percentage of the ventilating power required for rough-lined shafts. If the shafts have projecting frame sets, it pays to use concrete slabs between the frames or a gunited lining to minimize resistance to the flow of air.

The square turn from the fan drift at the surface into the shaft and another square turn at the bottom of the shaft into a single airway cause great loss of ventilating power at most mines. These turns should be carefully designed, with suitable curves that aid the flow of air. Experience in tunnel ventilation indicates it would sometimes pay to use curved deflectors.

Wherever possible, the air should be split into two parts at the bottom of the shaft, with easing curves to avoid the loss of energy that commonly results when the air current is throttled.

ARRANGEMENTS FOR VENTILATION AT SLOPE AND DRIFT MINES

Entrances or arrangements for ventilation usually are made more easily at a slope or drift mine than at a shaft mine. On the other hand, experience has shown that this very advantage has fostered negligent planning. Entrances at many mines have been made so close together that serious difficulties arose at the time of an explosion or fire, as smoke and fumes covered both openings. Moreover, there has been a tendency to make the coal pillars between the intake and return so thin that air leaks through crevices and the efficiency of ventilation is impaired.

Too often rooms have been driven close to the slopes, drifts, or main entries, or have been turned directly off them for the sake of easily obtained coal, so that in later work it has been difficult or impossible to drive the additional parallel airways needed for ventilating a large mine. Slope and drift openings should be separated by not less than 50 feet of rock or coal; at the points of entrance it is better to have 100 feet at least. Slope and drift entrances should be of concrete or of brick arched for at least 100 feet. No wooden building on the surface should be within 75 feet of any mine opening.

[33b] McElroy, G. E., and Richardson, A. S., Resistance of Metal-Mine Airways: Bull. 261, Bureau of Mines, 1927, 149 pp.

FANS

Some mine fans are arranged as pressure and others as exhaust fans; during recent years the latter have been more common. In the best practice, that necessary in gassy mines, the intake air enters, or downcasts, through the hoisting shaft or slope and the main haulage roads, and it returns, or upcasts, through the air shaft.

Many State laws now contain the commendable requirement that fans must be constructed to permit quick reverse of the ventilating currents to meet emergencies due to fires or explosions; they also require that fan casings have explosion relief doors and that fans be offset from the air shaft or air drift at least 25 feet from the projection of the nearest side, so that they will not be damaged by an explosion in the mine. Fireproof construction of fans and casings should be required.

Fans of larger capacity are being installed as mines become larger, more men are employed in a single mine, and the danger from inflammable gas increases as workings are deepened or are extended under thick cover.

Fans at gassy mines should have an auxiliary means of driving, such as a steam or gasoline engine stand-by; if they are electrically driven, a separate source of electrical power should be provided.

Fans with capacities of more than 250,000 cubic feet of air a minute against a pressure head of about 4 or 5 inches of water gauge have been installed at some coal mines in the United States. A few fans with double this capacity requirement have been erected at deep, extensive, gassy coal mines in Europe. There they usually serve to ventilate workings in a number of coal beds developed from the same air and hoisting shafts.

UNDERGROUND FANS

After electric power began to replace steam or compressed air in coal mining there was an increasing tendency to place fans underground. Some mining companies went so far as to place their main fans underground, but explosions that wrecked these fans have brought about general abandonment of the practice, and most State regulations or inspection departments require the main fan to be on the surface and in such a place as to avoid serious damage by explosions or fires. The usual requirement is to offset the fan 15 to 25 feet from the side of the shaft or drift and to provide either explosion-relief doors or a weakly constructed conduit. Well-designed explosion-relief doors are preferable to the latter.

ELECTRICALLY DRIVEN BOOSTER AND AUXILIARY FANS

Booster and auxiliary fans, first used extensively and appropriately in metal mines, have been installed underground in coal mines, especially of late with the introduction of certain types of concentrated mining methods. Many of these subsurface installations in coal mines are open to severe criticism, for coal mining is attended by dangers from which metal mining, with rare exceptions, is free.

Booster fans.—Booster fans are those that raise the pressure (positive or negative) of the air current or a split of the current at and from a point where the pressure imparted by the main fans (on the surface) is insufficient to force the air current into distant parts of the mine or through some restricted airways. Use of a booster fan is nearly always an indication that the main fan is not powerful enough or the airways are blocked or are too small. Under very exceptional conditions, however, a booster fan is a proper means of supplementary ventilation, but it should always be placed on the intake air and the entry should be fireproofed 50 feet from the fan in each direction. As a booster fan is always motor driven, the motor should be of sturdy construction, preferably inclosed, and the power cable leading to it should be armored. The fan motor should not have a self-starter; a fire boss should make an examination before an idle booster fan is started. It should run continuously unless stopped for repairs.

Auxiliary fans.—Auxiliary fans are small portable fans; virtually all are blowers and are electrically driven. They are used with canvas tubes or metal pipes to ventilate headings or narrow workings that are without crosscuts or cut-throughs or have them more than the normal distance apart. State regulations fix the maximum interval between crosscuts in entries, but some States do not specify the interval in rooms.

Fans and tubes have been substituted for line brattices in headings and rooms in mines supposed to be nongassy. As a matter of fact, they have frequently been used in headings and rooms that give off dangerous amounts of inflammable gas. So far the electric motors driving booster and auxiliary blower fans have not been flame proof, and hence they may readily ignite inflammable gas. Up to December, 1927, no fan motor had been approved by the Bureau of Mines.

Certain publications and trade journals have referred to the wide use of underground blowers and tubes in European coal mines, but one must remember that those blowers are driven by compressed air exclusively. Furthermore, in Europe no other workings are permitted to be turned off headings or slopes ventilated by compressed-air blowers and metal tubes until an air connection has been made with another heading or slope to establish an air circuit.

Even though explosion-proof electric motor or compressed-air motors are used to drive blowers it is still questionable whether blowers should be used in headings or rooms which give off methane in appreciable amounts. As now used many such blowers are shut off at the quitting time of the day shift and are started automatically or by hand-thrown switches the next morning. If methane accumulates during the night, forcing the body of gas into the air current of that part of the mine involves the danger of ignition through either a "short" or arc of a power wire, the failure of some piece of apparatus or some worker's error or careless act.

Many experienced mining engineers and coal-mine operators believe that this method of ventilation by blowers and tubes is necessary under exceptional conditions only, provided the workings are properly laid out. In a gassy mine an electrically driven blower creates a dangerous hazard. Exceptional conditions can be met most safely by using a blower driven by compressed air, the compressor being placed well back from the face in pure intake air. In any case the blower should be operated continuously to avoid gas accumulating.

When a blower is used, a tight line-brattice is desirable instead of tubing or in addition to it, so that there may be some circulation of air when the blower is shut down. A blower should not be used if the recirculation of air in the working place is more than 10 per cent of the current entering it. Recirculation is best prevented by requiring the split from which the blower intakes to have three or four times the volume forced by the blower, and the volume of the split should be at least 10,000 cubic feet a minute.

Electric motors, whether permissible or open, should not be used where there is more than 0.25 per cent of inflammable gas in the air current. Moreover, electric self-starters should not be used; then there will be no possibility of the blower starting until the place has been inspected for gas. If gas is present, the motor or a short circuit of the wiring may ignite it.

Policy of Bureau of Mines regarding auxiliary fans.—The Bureau of Mines recommends that auxiliary fans or blowers should not be used in coal mines as a substitute for methods of regular and continuous coursing of the air to every face of the mine.

COURSING THE AIR IN A COAL MINE

Good ventilation in coal mines can be assured only by having the airways in proper condition and keeping the velocity of the air moderate—that is, less than 1,800 linear feet a minute (20 miles an hour) in smooth-lined shafts and air courses, less than 900 linear feet a minute in ordinary rough-ribbed airways, and less than 600 feet a minute in haulage ways and manways. To keep down the velocity the airways must be large, or a number of parallel entries must be used.

Such restrictions on velocity keep the frictional resistance low, allow a continuous saving in power cost, lessen leakage, and make possible the ventilation of distant workings without resort to booster fans or a reduction in the amount of air.

On the other hand, the velocity of the air current of any one split should not be less than 200 linear feet a minute, and the volume of the split should not be less than 10,000 cubic feet a minute in order to dilute and to sweep away gases and provide the men with air that is within the limits of purity for health.

LAYOUT OF VENTILATION SYSTEM

MAIN ENTRIES OR SLOPES

Good practice requires at least three parallel main entries or slopes, even in a mine of small output; the middle entry, for intaking air, should be the haulage road; the others should be the main return entries for each side. Even better practice is a minimum of four parallel entries, the inner pair to be intakes (one for haulage and the other for a manway) and the outer pair to be main returns. One merit of this plan is that each pair can be driven with crosscuts or cut-throughs at the intervals specified by State laws. The pairs of entries need be connected only where branch entries start off, and the manway will therefore be more isolated from the haulage way which, because of the coal dust deposited in it, is nearly always the entry that is traversed most violently by an explosion.

The best practice in long-lived mines of large output is to use not less than three pairs of parallel entries for main entries, thus providing three entries for the intake and three for the return air.

BRANCH ENTRIES OR LEVELS IN PITCHING BEDS

Each main branch should have at least three parallel entries if they are to be long. In the Pittsburgh (Pa.), Fairmont (W. Va.), and Ohio fields some large mines that work flat-lying beds use four parallel entries as main branch entries, thus having two intakes and two returns.

Butt entries, panel entries, or panel slopes may have two parallel entries only where they are comparatively short, say, less than 1,200 feet long.

In pitching beds, panel-slopes to the dip and narrow rooms on the strike (that is, level) afford the best arrangement for ventilation, because the return air current can always be ascending. This layout is required in France, Germany, and Belgium, because methane, which is lighter than air, will be swept away by the ventilating current more easily than if the rooms or headings "go to the raise," for then the gas tends to accumulate above the last crosscut in any room or heading.

LONGWALL VENTILATION

It is a common practice in the United States to use the upper of a pair of levels in a steeply pitching bed as a temporary air course called the "counter" and to short-circuit the air through rooms to the level above, the coal being loaded through chutes into cars on the lower level. This plan tends to produce dusty conditions and leakage of air. It is better practice to use the upper level for loading and haulage and carry most of the intake air to the entry heads, in the lower of the pair. In gassy mines the best practice is to use a panel system with level narrow rooms, retreating with the pillars, or still better to use retreating "step-face" longwall.

Longwall methods of mining, which are so widely used abroad, have been little employed in the United States as yet, and the advancing longwall method is not well adapted to the natural conditions in this country. Retreating longwall methods, especially panel retreating, are better adapted to conditions in our coal fields. Effective ventilation in full advancing longwall, as found in the longwall mines of northern Illinois, is a simple matter, but in retreating longwall is not so easy. In planning ventilation care must be taken to insure enough splits of air and, if falls block the face, the diversion of the air current through parallel entries or crosscuts, so that it will reach the face on either side of the fall.

OVERCASTS, DOORS, REGULATORS, AND STOPPINGS

The layout of the ventilating system of every coal mine should require the least possible use of ventilating doors. Multiple airways and overcasts can be substituted; they also allow separate ventilating splits to be made without using the return air (perhaps containing a dangerous amoúnt of gas or deficient in oxygen) of one pair of branch entries as the intake of another pair of branch entries.

Overcasts.—Overcasts should be substantial and fireproof. Some mining men have thought it well to build flimsy overcasts that would be blown out by an explosion, thus relieving the pressure and checking the explosion. The experience of the bureau in its investigations of every explosion disaster since 1908 has been that flimsy overcasts do not check the explosion; on the contrary, wooden overcasts are a menace, because if they catch fire a part of the mine is cut off from ventilation. It is true that the most substantial overcasts are likely to be blown apart by a violent explosion, but substantially-built overcasts have withstood weaker explosions. If the mine is rock-dusted in the manner described on later pages, the explosions ought not to develop enough pressure to blow out well-constructed overcasts. Main overcasts should be carefully designed with ample airways overhead and with easy curves for the flow of air. Overcasts as too often constructed throttle the air current so as to reduce its volume greatly and therefore cause a loss of power. When conditions permit, as sometimes is the case in pitching beds, overcasts can be made by driving overhead at the crossing and leaving natural strata between.

Ventilating doors.—Every coal mine must have a certain number of ventilating doors. Main ventilating doors on main roadways should be carefully installed with the frame, preferably of concrete, hitched well into the ribs. The doors should be of two thicknesses of matched boards, one thickness placed diagonally, with building paper between them. The doors should be so hung as to be self-closing unless they are arranged for efficient mechanical opening and closing. They should fit tightly against the side of the frame; they should not fit inside it, for then they are liable to wedge and stick if the doorframe settles.

Mechanically operating doors have proved very successful under some conditions. They should be of such a type that high pressure of the air on one side will not prevent their being opened. Usually this result has been accomplished by having one-half of the door open inby and the other half outby. The doors are opened by levers operated automatically by a train of cars when it approaches the doors. In another type compressed air or hydraulic pressure in a cylinder actuates mechanisms that open and close the door through the throwing of a lever, usually by the trip rider. Doors on all main haulage roads and main air courses that carry the whole air current or large splits of such air courses should be in triplicate.

In a gassy mine at those points where the doors control the current of an entire split of air they should be in sets of two or more with enough space between to allow for the passage of trips or trains of cars, so that not more than one door in a set will be open at the same time. Single doors should be used only in short-room entries to carry the air current up to the faces of the rooms. Curtains should not be used where doors can be installed; they may be used as checks in room entries or in the mouths of rooms to maintain circulation into the faces of rooms. Curtains thus used should be of heavy, strong, closely woven cloth, hung carefully and kept effective.

In gassy mines line brattices should extend from the last open crosscut to within 10 or 12 feet of the face and should be supported at top and bottom by boards nailed to a line of posts.

Regulators.—Usually the proportions of the ventilating splits can be arranged so that the necessary number of regulators is small, but at least one-half of the splits of air generally require regulators to prevent their receiving an undue proportion of the main air current. A good type of regulator is a brick or concrete stopping with a rectangular hole that allows plenty of room for the passage of a man and has a horizontal slide to permit close regulation of the air current passing through. The proper position of the slide should be plainly marked by the mine foreman or responsible official. Some regulators are placed in doors, but this is not good practice, as a door is likely to be opened for men to pass or may be left open and thus permit short-circuiting of the air current.

Stoppings.—All stoppings in crosscuts of main entries and slopes should be substantially built of incombustible material and hitched into the floor (if it is of clay) and the ribs. If stoppings are made of brick, blocks, or rubble they should be covered with cement plaster, and the ribs in the immediate vicinity should be plastered to prevent leakage.

When temporary stoppings are built in short-lived room entries and in rooms where the air pressure is low, they may be of tightly fitted boards. The best method of making these stoppings tight is to use boards which lap, leaving the lap edge upward and leveling it inward to provide a recess for making a plaster seal.

Gob stoppings are permissible in room entries or rooms. In room entries the stoppings should be faced up on one end and plastered, as the leakage of air through gob stoppings is very great. In a place where roof pressure is excessive because of great depth below surface or a local squeeze the best form of stopping is made by piling short logs to the roof longitudinally, then driving in long wooden wedges. Such a stopping will compress without rupture, and in case of fire the ends will char, but the burning will not go deep.

Fire stoppings and stoppings used to seal off abandoned workings should be substantial, preferably be built of concrete, and have two pipes extending through them, one at the top and one at the bottom, fitted with valves. These pipes are necessary for testing for gas pressure and for draining off water if its pressure becomes too heavy.

In gassy mines stoppings for extensive abandoned workings should be as strong as a concrete stopping at least 16 inches thick. If the abandoned workings give off a large amount of gas, a borehole should be drilled from the surface into the highest point to draw off the gas. If the workings are too deep, as in mountainous country, it may be necessary to pipe the gas into a return airway which is traversed by fire bosses only.

Cloth stoppings should be used only temporarily, as in the last but one crosscut, until a tighter and more permanent stopping can be erected.

To make an excellent form of temporary stopping, fasten a brattice cloth to a frame, put chicken-wire netting in front of it, pin the netting and cloth together with long wire nails, and apply with a cement gun a thick layer of cement sand, about 1 inch thick, but thicker at the corners. This thin reinforced stopping is air-tight, fireproof, and of considerable strength.

SEALING OLD WORKINGS

The Bureau of Mines recommends that in coal mines all entries, rooms, panels, or sections that can not be kept well ventilated throughout or can not be inspected regularly and thoroughly, or that are not being used for coursing the air, travel, haulage, or the extraction of coal, be sealed by strong fireproof stoppings.[34]

EXPLOSIBILITY OF COAL DUST

Coal dust propagates all great mine explosions. Gas causes local explosions and inflammations which individually kill or injure a few or a small group of men in the vicinity, but coal dust is responsible for the sweeping explosion disasters in bituminous mines. This fact has been fully demonstrated by nearly 1,000 explosion tests in the experimental mine of the bureau near Pittsburgh, Pa.

Pennsylvania anthracite dust in which the ratio of volatile to total combustible matter is less than 10 per cent is fortunately not explosive in air; hence many Pennsylvania anthracite mines, though very gassy, have experienced only local, though sometimes violent, explosions of gas, since large bodies of explosive gas are rarely more than local in ventilated mines.

The Bureau of Mines in its statistics of coal-mine accidents has segregated major explosions from minor explosions, designating as minor explosions those that cause less than five deaths. Such minor explosions may be caused by either gas or bituminous coal dust or by both; they may be local or may be shot-firers' explosions, some of which are widespread but occur when only a few men are in the mine.

In bituminous mines virtually all the major explosions—those in which five or more men are killed—are propagated by coal dust. In the United States the number of these major disasters in any one year between 1900 and 1925 has ranged from 2 in 1900 and 1 in 1921 to 13 in 1910. The number of men killed in any one year is a matter of exposure—that is, the number of men in the mine at the time of each explosion—and does not necessarily indicate the relative violence or extent of the explosions in that year. The number killed annually has ranged from 16 in 1921 to 868 in 1907. In the 5 years

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[34] Mine Safety Decision No. 6.

1922 to 1925, the major explosions and the resulting deaths in each year were as follows:

Explosion disasters in bituminous coal mines in the United States

Year	Explosions	Killed
1922	12	269
1923	8	286
1924	9	444
1925	12	253
1926	13	327

RELATIVE EXPLOSIBILITY OF COAL DUSTS[85]

Intensive investigations in the experimental mine of the Bureau of Mines have determined these principal facts regarding the relative explosibility of coal dust and mixed coal-mine dusts.

All coal dusts, except anthracite dusts, if in a sufficiently dense cloud in air, may be ignited by a flame or electric spark and may produce a violent explosion.

"Explosive" coal dust is of a size that will pass through a 20-mesh sieve, so the maximum diameter of the particle is about one-thirtieth of an inch. The mine dusts in semianthracite, semibituminous, bituminous, and subbituminous mines differ in explosibility according to five factors:

1. Percentage of noncombustible in the dust as found.
2. Percentage of external water mixed with the mine dust.
3. Percentage of fine coal dust in the mixture. That passing through a 200-mesh sieve is used as a measure of fineness.
4. Percentage of volatile matter in the combustible content of the dust, more commonly known as the volatile ratio.
5. Percentage of inflammable gas in the mine air.

Considering these five factors separately:

1. **Percentage of noncombustible.**—A mine dust, to prevent its propagating an explosion (no fire damp being present), must contain from about 20 per cent in a low-volatile or semianthracite dust to 75 per cent noncombustible in the case of a high-volatile very fine size of coal dust. In samples of mine dust it is impossible to distinguish between the ash of the coal dust and the inert dust mixed with it by natural agencies. External ashy material or rock dust has greater effect in absorbing heat than the inherent ash of the coal, but it is not practical to separate in sampling.

2. **Percentage of external water.**—Small percentages of external or free moisture—that is, not inherent in the coal as water of composition or held in pores—has the practical effect on the explosibility of dust projected into the air of so much incombustible, but in larger proportion there is a physical effect of causing the dust to adhere together or to stick to the floor, ribs, and timbering, so that the dust will not be capable of being raised by air waves into the air as a dust cloud and propagation of an explosion will not occur in that place.

If, however, fine inflammable dust is carried along by the advance air waves in sufficient amount, the explosion may be propagated through a wet zone.

[85] This statement regarding the relative explosibility of dusts is taken from Effective Rock-Dusting of Coal Mines, by George S. Rice, Information Circ. 6039, Bureau of Mines, 1927, 7 pp.

The percentage of free moisture in the mixed dust that will prevent it rising as a dust cloud at the inception of an explosion varies from 15 per cent for coarse dust to 30 per cent for the finest-sized dust.

The method of wetting coal dust to prevent propagation of an explosion has failed because of the rapid drying of the coal dust. Humidifying the intake has also failed because high relative humidity or even saturation of the mine air does not prevent an explosion from propagating in coal dust.

Watering at the face, however, and the use of sprays on cutter bars of mining machines, also sprinkling the tops of loaded cars, lessens the distribution of dry coal dust, and hence less frequent rock-dusting is required.

3. **Percentage of fine coal dust.**—The finer the size of coal dust in air the more explosive it is. The criterion of fineness used by the Bureau of Mines is the percentage of dust passing through a 200-mesh sieve. A coarse mine dust—say, 10 per cent—passing through 200 mesh may require for an explosive dust like the Pittsburgh bed coal dust 50 per cent incombustible to render it harmless; whereas a fine size of such dust may require 75 per cent incombustible.

Most untreated mine dusts from top, sides, and floor, it is found from sampling hundreds of mines, average in size 20 per cent through 200 mesh. Rib and timber dust samples, however, are usually much finer, and if there are considerable amounts containing over 5 or 6 ounces of pure coal dust per linear foot of passageway, then an increase of incombustible may be needed to prevent propagation of an explosion up to the percentage required for the fine (pulverized) coal dust of the specific kind.

It has been demonstrated by tests that a coal-dust explosion may be propagated by timber and rib dust containing a large proportion of pure coal dust, even if the bottom or floor dust is not an explosive mixture; and the reverse is also true, that a floor dust rich in coal dust may propagate an explosion, although the ribs and timber have been rock-dusted, unless the cross timbers are so laden with rock dust as to act like rock-dust barriers. Hence, the necessity of sampling separately dust from the timbers and ribs from dust on the floor of mine workings to determine when there is need of cleaning and of another rock-dusting.

4. **Percentage of volatile combustible matter.**—The percentage that the volatile combustible matter is of the total combustible (commonly spoken of as the volatile ratio) is a most important factor in comparing the explosibility of mine dusts of different composition. The Bureau of Mines uses as a measure of this factor the per cent of incombustible in a dust (ash plus moisture) which will just prevent propagation of an explosion by a specific coal dust. The limiting percentage varies from 20 per cent incombustible to render a semi-anthracite nonexplosive to 75 per cent for a high-volatile coal dust of the finest size. With coarser dust, such as most often found in mines, 20 per cent through 200 mesh, the requirement, when no appreciable amount of fire damp is present, is about 65 per cent (ash plus moisture) for an average high-volatile coal dust.

5. **Percentage of inflammable gas.**—The effect of methane in air below the lower explosive limit of the methane-air mixture, about 5.2 per cent, is that, to prevent propagation, an increase of incombustible in the dust is required in direct proportion to the percentage of methane. The increase varies from 3 per cent incombustible in the finest size of high-volatile coal dust to 10 per cent for dusts of low-volatile coals, which without any methane present have a low order of explosibility.

Conclusion.—From a study of the foregoing factors in the relative explosibility of different coal dusts it is evident that while each of the different factors has a wide range of values and some combine to increase while others tend to decrease explosibility of a given mine dust, the only safe procedure in the preventing of disastrous explosions is to rock-dust thoroughly in every accessible part of a mine. Rerock-dust immediately when the content of either floor dust or rib and timber dust falls to 55 per cent in any zone in the mine and maintain at all times the average noncombustible content of the mine dust above 65 per cent

ROCK-DUSTING AS A PREVENTIVE OF COAL-DUST EXPLOSIONS

Coal-dust explosions can certainly be prevented; it has been proved conclusively that adequate rock-dusting will preclude their initiation or propagation. Since 1921 rock-dusting or stone-dusting has been mandatory in British coal mines not naturally wet. Only local explosions have occurred since in the rock-dusted mines,[36] whereas there were several disastrous explosions prior to 1924 in coal mines assumed to be wet. Now, anthracite mines alone are exempted from rock-dusting, and the only exceptions in bituminous mines are those places where the coal dust on walls and floor carries 30 per cent of moisture. Such a mixture would be liquid mud and would be virtually impossible to maintain in the average well-ventilated coal mine, for the air current rapidly carries the moisture away.

France has officially approved (1919) rock-dusting and requires it in certain classes of mines. Since April 1, 1926, the Ruhr coal mines, Germany, have officially been required to employ rock-dusting because some disastrous explosions happened in mines using water to render coal dust inert.

The Bureau of Mines, as a result of large-scale tests in its experimental mine, determined in 1913 that rock-dusting was effective and said so in its publications. Nearly all American coal-mining men, however, adhered to watering or humidifying methods until 1924, when, after some severe explosion disasters, they began to introduce rock-dusting, at first slowly, but more rapidly during 1925 and 1926.

Local gas explosions occurred in seven rock-dusted mines between January 1, 1926, and May 1, 1927; out of 2,151 men in these mines only 57 were killed; 2,093 escaped.

Specifications for rock-dusting were formulated by the bureau and issued in May, 1924, as Reports of Investigations, Serial 2606. These specifications are as follows:

TENTATIVE BUREAU OF MINES SPECIFICATIONS FOR ROCK-DUSTING TO PREVENT COAL-DUST EXPLOSIONS IN MINES[37]

Standard rock dust for use in the rock-dusting of coal mines might be defined tentatively as powdered mineral, light colored, and free of carbonaceous mat-

[36] One explosion disaster occurred in a rock-dusted mine in South Wales in 1927. The initial explosion, which started in gas, was limited, but the ventilating system was deranged, and many were overcome by afterdamp.

[37] By George S. Rice, chief mining engineer; J. W. Paul, senior mining engineer; and R. R. Sayers, chief surgeon, of the Bureau of Mines.

ter and free silica, all of which will pass a 20-mesh screen while 50 per cent of it will pass through a 200-mesh screen.

Such dust may be prepared from limestone, gypsum, anhydrite, or shale free of sand and flint. For the initial rock-dusting of the average nongaseous bituminous mines enough standard rock dust should be applied so that the combustible content of the resulting mixture of rock dust with mine dust shall not exceed 45 per cent, a range somewhere between 35 and 45 per cent being the practical objective sought. All entries, slopes, or passageways and rooms necks should be rock-dusted.

Additional safeguards are: (*a*) Rock-dusting rooms; (*b*) scattering of dust in vicinity of shots before firing; (*c*) placing of barriers in the mouths of panels, cross entries, and other key positions.

Redusting becomes necessary whenever the combustible content of the mine dust exceeds the permissible maximum. This should be determined by regular, systematic sampling, followed by a simple analysis of the samples for combustible content. A Bureau of Mines volumeter for measuring the density can be used for the determination of combustible content.

In gaseous mines from 5 to 10 per cent additional incombustible is required for each per cent of methane present in the air current.

Detailed specifications.—Specifications for size and character of rock dust to be used in coal mines as a means of preventing disastrous explosions have not yet been standardized by the Bureau of Mines, but so many inquiries have been received from mining operators and engineers who are considering adopting rock-dusting for their mines that this memorandum has been prepared.

1. *Size of dust particles.*—The finer the size of particles of rock dust the more easily is it raised in the air with coal dust to prevent the propagation of flame, if enough rock dust is used proportional to the kind of coal dust found in any given mine.

Only such particles of either coal or inert material that will pass through a 20-mesh sieve are considered to be dust. Thus, dust—whether coal dust or rock dust—would include particles ranging from 20 mesh (roughly about one thirtieth of an inch in diameter) to the finest microscopic size. However, mine road dust that passes through a 20-mesh sieve will vary widely in its proportion of the finest dust and correspondingly in its explosibility. From experience in tests at the experimental mine the Bureau of Mines has adopted that percentage of dust by weight that passes through a 200-mesh sieve for the criterion of the most explosive size of any coal dust, also of the most effective size of inert dust to limit an explosion.

Also, the bureau's experience is that rock dust should be ground until 50 per cent will pass through a 200-mesh sieve, but a dust having a smaller percentage through 200 mesh may be used, provided (*a*) that at least 30 per cent passes through 200 mesh, and (*b*) that a proportionately larger amount of the dust is used. For example, if the unit of weight of the finer dust required be represented by 1, the quantity of dust having 30 per cent through 200 mesh would be determined by the proportion:

$30:1::50:x$ (x being the quantity required of dust 30 per cent through)

$30x=50$

$\frac{x=50}{30}= 1.7$ or 1.7 times as much should be used as of the dust 50 per cent through

These specifications are similar to those of the British standards of size as defined in their regulations, except in giving a slightly coarser dust. The British maximum size is 28 mesh, and although the criterion of the finest size is that passing through their standard 200-mesh sieve, this size corresponds to the size through the usual American standard screen of 250 mesh.

2. *Character of rock dust.*—(*a*) As concerns composition and physical properties of the rock dust, less than 2 per cent combustible material is desirable, and it should not be as much as 10 per cent. If the inert dust contains any combustible material, 1 per cent increase in amount of dust should be used for each per cent of combustible material.

(*b*) Rock dust should be as light in color as possible, both to permit ready observation of freshly distributed coal dust from the regular coal production operations of the mine and to increase the illumination of the passageways, which tends to prevent accidents arising from poor illumination.

(*c*) Rock dust should not contain an appreciable amount of siliceous particles, and dust from sandstone and dust from sandy shale should not be used. Dusts from pure limestone, dolomite, gypsum, and anhydrite are preferable. The dust from roof shale free from gritty material is extensively used in Great Britain, but not all roof shales are suitable; often they are too sandy or contain too much combustible matter. The Bureau of Mines is prepared to advise operators as to the suitability of the material or rock to be pulverized for coal-mine dusting. Such advice may be obtained by submitting a sample of the material to the Bureau of Mines experiment station at Pittsburgh, Pa., where chemical, petrographic, and physiological tests will be made.

3. The quantity of rock dust that must be used for initial dusting for any particular stretch of passageway depends upon:

(*a*) The character of the coal, whether high volatile or low volatile.

(*b*) Size of particles of the coal dust found on the road ribs and timbers as determined under specification 1.

(*c*) Percentage of inert matter naturally present; that is, moisture and ash of the coal and ash of dust from the roof, partings, and floor that has become mixed with the coal dust.

(*d*) Quantity of road and rib dust in the specified stretch of passageway before rock-dusting.

General information on factors (*a*) and (*b*) can be obtained by studying results of tests of various coals in Bureau of Mines Bulletin 167 or by applying directly to the bureau.

Factors (*c*) and (*d*) can be determined only by systematically sampling the dust in that part of the mine to be rock-dusted in such a way that the quantity per linear foot of passageway can be estimated approximately. Practically, however, the way to start is to clean up a stretch of passageway and rock-dust it, then from time to time sample the resulting mixture.

4. *Redusting.*—After the initial rock-dusting samples should be taken at regular intervals to ascertain how rapidly coal dust is accumulating and from the analysis to determine whether or not additional rock-dusting should be done and whether cleaning up is necessary before redusting.

The rapidity with which coal dust is made in any mine varies with the friability of the coal, method of mining, and, most important of all, the spillage of coal in transportation by leaky cars and in "topping" the cars too much. These factors, taken with the character of the coal dust and the amount of natural rock-dusting, make the quantity needed for continued dusting of a particular mine or district of a mine difficult to estimate without some trial. Some parts of an entry must be dusted every week; in other parts of a mine redusting will last for several months. In British mines the quantity of rock dust used daily in any one mine varies, according to the conditions and size of the mine, from 5 to 20 tons in the largest mines.

5. *Maximum permissible percentage of combustible in road dust after rock-dusting.*—It is not possible, as indicated above, to state the maximum permissible percentage of combustible content in road dust applicable to all mines. The amount depends on many factors and ranges from 75 per cent for semi-anthracite to only 25 per cent for certain pulverized high-volatile dusts. Conversely, the minimum percentage of incombustible content that will prevent explosion propagation ranges from about 25 per cent for the least explosive to 75 per cent for the most explosive. If fire damp is present in any part of the mine, a greater percentage of rock dust must be used than in a mine practically free from gas. Therefore, it is not possible to lay down a hard and fast rule that will apply to all the different conditions and characters of coal dusts found in the mines of the United States.

The British law says the dust on floor, roof, and sides throughout shall always consist of a mixture containing not more than 50 per cent combustible matter. In other words, there must be 50 per cent incombustible matter.

The results of testing coal dust from various mines of the United States, in the experimental mine, indicate that although 50 per cent of incombustible material (total ash plus moisture) will prevent ignition of many natural mine-dust mixtures, with no fire damp present it will not suffice if some fire damp is present; and it will not prevent propagation of an explosion when strongly started, as by gas and coal dust at the face. To meet such contingency, from 55 to 65 per cent incombustible matter is required to prevent propagation; and if 1 or 2 per cent of fire damp is present in the air current 5 to 10 per cent additional incombustible must be used.

However, it must be remembered that the British regulation sets a maximum of combustible matter in any part of a mine, and to meet this regulation it is found that the average combusible in the treated road dust of British mines will range from 40 to less than 30 per cent combustible, or conversely have 60 to more than 70 per cent incombustible.

Further, it must be remembered that the average natural road dusts in American mines, as determined by thousands of samples, usually contain more than 20 per cent incombustible (ash plus moisture) and sometimes 30 to 50 per cent, so that an additional amount of rock dust equal to the amount of coal dust present in a passageway (after it has been well cleaned up) may be sufficient ordinarily, and sometimes a very small amount may suffice.

Subsequently, the amount required to keep the roadways safe will depend on the control by the mine management of the production of coal dust. Rib and timber dust is much finer than road dust and contains less incombustible matter, consequently it requires a larger proportion of rock dust to make it safe against the propagation of an explosion; moreover, it is in a position which makes it easily brought into suspension as a dust cloud. In rock-dusting effort should be made to supplant the coal dust on timbers and rib projections; then the coal dust which is subsequently made and carried by air currents till it falls on these places will tend to roll off, as the angle of repose of coal dust is less steep than that of rock dust.

6. *Sampling.*—One of the greatest advantages of the method of rock-dusting is that the danger or freedom from danger of explosion propagation through the agency of mine dust can be determined by sampling that part of the mine under suspicion and analyzing the samples. This more or less positive ability of determining the degree of safety during a period of some days or weeks is invaluable to the mine operator and the State inspector, as systematic records of the condition of any part of a mine can be made.

The method of sampling in a roadway requires further development. The Bureau of Mines has heretofore been using a special sampling scoop with screen and brush to take a sample of the dust about 8 inches in width across the roadway, on ribs, and on overhead timbers. All coal passing over a 10-mesh sieve is rejected in the mines. Before analysis the sample is dried, if necessary, and is then screened in the laboratory through a 20-mesh screen and the oversize rejected. This gives a fair sample of the dust at any one cross section of the passageway. Investigations are now being conducted to develop a portable vacuum-cleaner device, not requiring electricity, for such sampling.

To a certain degree such small samples are grab samples, but if they are taken at regular intervals along the passageway they give a fairly accurate average for the distance examined. An official test of this was made at the Bentley colliery, Yorkshire, England, in which a comparison was made of an average of the analyses of many small samples in a given stretch of entry with the analysis of a gross sample obtained from shoveling and sweeping up the entire dust in that same length of roadway. The ash content by the two methods agreed within a few per cent, so the many small samples were regarded as fairly representative of the dust in the passageway.

7. *Analysis of road-dust samples.*—A comparatively simple fire analysis will determine the total combustible of a mine dust except when limestone is used or other dust that looses carbon dioxide or water of composition. For such dusts these losses must be determined and added to the noncombustible material.

The Taffanel volumeter, modified by Fieldner, of the Bureau of Mines, is a device for quick determination of the combustible content. It is based on density of the incombustible material. Tests have indicated that it is accurate within a few per cent.

8. *Extent of rock-dusting necessary in a mine.*—Questions are repeatedly asked, such as, " How extensively is it necessary to carry rock-dusting through the mine to prevent an explosion?" " Is it necessary to rock-dust rooms?" " Is it necessary to rock-dust entries?" In the opinion of the bureau engineers, it is necessary to rock-dust all passageways that contain any coal dust whatever. It is not enough simply to rock-dust the rooms. Many of our most disastrous explosions have started in entry ways, and even near the mouth of the mine, through ignition of coal dust by electric shorts from trolley wires or power lines or by explosions of bodies of gas forced into the entry from adjacent workings.

There is always the possibility of ignition of fire damp from one cause or another. Therefore, to prevent ignition of coal dust in a particular locality is not sufficient; the dust must be so generally neutralized as to prevent propagation of an explosion of a body of fire damp or of locally untreated or insufficiently treated coal dust.

The first step should always be to rock-dust the haulage roads, and dusting should be carried into the cross entries, subsidiary entries, and air courses. The next step is to rock-dust the room necks and then gradually extend the rock-dusting up into the rooms. Rock dust close to the faces, although desirable, is not so vital as thoroughly dusting the entries, because an explosion starting in a room will die away on well rock-dusted entries.

9. *Rock-dust barriers.*—The Bureau of Mines engineers believe that an additional measure of safety is to install rock-dust barriers at the mouths of all panels, cross entries, and other key positions, but the barriers should fulfill

the specifications suggested by the bureau in Technical Paper 84[38] to insure operation. Barriers should not be regarded as sufficient in themselves or as the most important feature. General rock-dusting is much more important; the barriers should be considered only as secondary defenses.

NOTE.—The British and French methods of rock-dusting are described in Bureau of Mines Bulletin 225.[39]

In 1925 the increasing use of rock-dusting in coal mines prompted the American Institute of Mining and Metallurgical Engineers to appoint a committee of its members (the American engineering standards committee) to formulate a code of standard practices. This code was approved as a standard on December 30, 1925, and is the same in principle as that formulated by the bureau. The two codes cover different details but are in harmony with one another.

AMERICAN ENGINEERING STANDARDS COMMITTEE RECOMMENDED STANDARD PRACTICES FOR ROCK-DUSTING

In 1925 the increasing use of rock-dusting in coal mines and the variety of ideas of applying the method led the American Engineering Standards Committee to request the American Institute of Mining and Metallurgical Engineers to "sponsor" the work of the "sectional" committee on rock-dusting, the committee being made up, in accordance with the procedure of the American Engineering Standards Committee, of (*a*) Manufacturers (makers of equipment); (*b*) employers (purchasers, owners, users of equipment) (coal operators); (*c*) employees; (*d*) governmental bodies having regulatory power or influence over the field in question; (*e*) qualified specialists, such as staff representatives of technical societies, consulting experts with no exclusive business affiliation, and educators; and (*f*), insurance representatives.

The committee's recommendations as given below were accepted by the American Institute of Mining and Metallurgical Engineers and were approved December 30, 1925, by the American Engineering Standards Committee. This code is the same in principle as that formulated by the Bureau of Mines, as given on previous pages. The two codes cover different details but are in harmony with one another.

1. **Definition of terms used.**—The term "mine" shall include all underground excavations from which coal is hoisted or transported to the surface through one or more openings.

The term "main haulage" shall include all underground slopes and planes, all rock tunnels, and all entries excepting those from which rooms or chambers are turned.

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[38] Rice, G. S., and Jones, L. M., Methods of Preventing and Limiting Explosions in Coal Mines: Tech. Paper 84, Bureau of Mines, 1915, 45 pp.

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

The term "entry" shall include all underground haulage ways, traveling ways, and airways, excepting working places as defined below

The term "working places" shall include (*a*) rooms or chambers from the entry or gangway rib to the face of the room; (*b*) entries from the outside of the last crosscut turned to the face of entry; (*c*) crosscuts or break-throughs which are being driven between entries or rooms; (*d*) all pillar work.

The "return air" is the ventilating current, or split of same, from the point of passing the last regular working place in the section of the mine which it has been ventilating since leaving the intake to the point of union with the main return.

"Exposed electric circuits" means any conductor or conductors of the electric circuits in the mine, other than trailing cables of permissible machines, which by virtue of their location are liable to be damaged by falls of roof, wrecks etc., which may cause sparks or arcs in the mine atmosphere.

An "isolated panel" is a separate portion of a mine, consisting of one or more room headings, surrounded by a continuous pillar except where connected with the rest of the mine by not more than two sets of haulage and airway entries.

2. **Mines to be rock-dusted.**—All mines producing bituminous coal or lignite of any grade, and which are subject to the inspection of any State inspection service, shall be rock-dusted, unless all fine coal particles on the floor, ribs, and roof or timbers are in a muddy condition.

NOTE.—All mines producing coal other than anthracite, whether gaseous or not, are liable to dust explosions. The rock-dusting of each mine is a separate problem and must be carefully studied. Rock-dusting will be most efficient in mines using the isolated panel or longwall systems.

3. **Kind of dust to be used.**—The kind of dust to be used shall be as specified by United States Bureau of Mines and subject to the approval of the State mine inspection service. It shall not contain more than 5 per cent of combustible matter, nor more than 25 per cent of quartz or free silica particles, nor absorb moisture from the air to such an extent as to cake and destroy its effectiveness as a dry dust. It may be made from limestone, dolomite, gypsum, anhydrite, shale, talc, adobe, or other inert material which meets the foregoing specifications. The lighter-colored dusts are to be preferred.

4. **Size of dust to be used.**—The dust to be used shall be pulverized, so that 100 per cent will pass through a sieve having 20 meshes per linear inch, and 50 per cent or more will pass through a sieve having 200 meshes per linear inch (40,000 perforations per square inch).

5. **Parts of mine to be dusted.**—Rock dust shall be distributed on all main haulages, all entries to the last break-through, in all rooms and pillar workings to within 40 feet of the face or to the last break-through, and in all return airways where hauling or traveling is done. Dust must be distributed upon top, bottom, and sides of places.

In isolated panels in which no exposed electric circuits or nonpermissible motors are used, and in which only permissible safety lamps and permissible explosives are used, protection may be given by rock-dusting the entries and by rock-dust barriers at each entrance and exit.

In other places in which no traveling or hauling is done the rock dust may be distributed by the air current into which it is blown, provided that the amount specified in article 6 is deposited, or they may be protected by rock-dust barriers, which shall be of types as specified by the United States Bureau of Mines and subject to the approval of the State mine inspector service. These barriers are to be erected where they will stop an explosion either before leaving or entering each panel or section of a mine. The locations of the rock-dust barriers should be shown on the working mine maps.

NOTE.—Under this requirement all parts of the mine in which open lights, exposed electric circuits, or nonpermissible explosives are used must be dusted.

6. **Amount of dust to be used.**—In all places where rock dust is distributed enough shall be used so that the percentage of incombustible material in the samples of dust collected in the places shall be maintained at least 55 per cent. Along room entries or gangways where methane gas is found in the ventilating current the amount of incombustible material above specified shall be raised 10 per cent for each 1 per cent of gas. Where rock-dust barriers are installed the amount of dust used shall be at least 100 pounds per square foot of average cross section of entry at the barrier zone.

7. **Sampling dust.**—After a mine, or any part of a mine, has been rock-dusted samples of the road, rib, roof, and timber dust shall be taken from time to time to determine if that part of the mine requires redusting, under the following circumstances and procedure:

(*a*) A sufficient number of samples shall be gathered in the course of a month from various parts of the mine to obtain a record of the general dust conditions, provided the points of sampling are separated not in excess of 1,000 feet measured along the entry or air course. Samples should be taken at points which appear to represent average conditions.

(*b*) Sampling shall also be done when by visual inspection the dust in a stretch or zone of entry 100 feet or more in length appears to contain coal dust in an amount that may make the incombustible content of all the dust in that zone less than 55 per cent.

(*c*) A sample shall be taken in the following manner: A groove 6 inches wide across the floor from rib shall be made in the loose fine material by scoop or other means, also a 6-inch strip of dust shall be brushed from both ribs and the roof (if dust is adhering to the roof) and where the entry has timber sets from the top of one collar also 6 inches wide from the lagging (if any). All of the material thus gathered, and which may be conveniently gathered on a canvas or oilcloth, shall be screened through a 10-mesh screen, and that passing through this screen shall be put into a can or sack suitably labeled and be sent to the laboratory for screening through a 20-mesh screen and weighing, to determine the approximate amount of dust, per 6 inches, and for analysis or testing for incombustible content. The floor sample shall be kept separate from the rib, roof, and timber samples and separate determinations made.

(*d*) The dust in all barriers shall be inspected monthly and be kept in such condition that when the barrier comes into play the dust will fall loosely into the air.

NOTE.—The percentage of incombustible matter in the samples may be determined by the volumeter, as outlined in the United States Bureau of Mines Technical Paper 144,[40] or by chemical analysis, using the method recommended by the United States Bureau of Mines.

8. **Record of sampling.**—A written record shall be entered in a book kept for that purpose in the mine office, showing the location at which samples have been taken and the results of the analyses. A map of the mine should be kept posted to show the extent of rock-dusting and the location of rock-dust barriers.

NOTE—The practice of wetting bug dust or machine dust by the use of sprays on the machine cutter bars is recommended. The practice of wetting mine cars in transit by automatic drenching sprays is recommended.

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[40] Fieldner, A. C., Selvig, W. A., and Osgood, F. D., The Quick Determination of Incombustible Matter in Coal and Rock Dust Mixtures in Mines: Tech. Paper 144, Bureau of Mines, 1918, 36 pp.

LIABILITY-INSURANCE UNDERWRITERS APPROVE ROCK-DUSTING

Having become convinced of the efficacy of rock-dusting, liability-insurance companies have allowed discounts on premiums for mines that employ rock-dusting. Effective October 1, 1926, the Associated Companies of Hartford, Conn., declined to insure bituminous coal mines that do not rock-dust.

METHODS OF APPLYING ROCK DUST

Rock-dusting is done by hand, by compressed air, and with blowing machines. The hand method is largely employed in Europe but would be impracticable in this country because of its cost.

The compressed-air method is used to some extent in Europe; the rock dust is ejected from portable funnels connected to compressed-air lines. As compressed air is rarely used in American coal mines, the method is, with rare exceptions, impracticable in this country. However, there is a field for the development of a portable compressed-air machine which may have advantages for applying rock dust in air courses without tracks or in other trackless places, as along the goaf or "gob."

Rock-dust blowing machines, used in connection with a dust bin, mounted on a truck and having the fan and other mechanism driven by a chain belt from the wheels, are employed to some extent in British mines. These cars are pushed by men or drawn by ponies but are too small and slow for American conditions.

The first electrically operated rock-dust blowing machine using a fan was developed in a Colorado mine about 1912, but later went out of use. Since 1924 numerous electrically operated rock-dusting machines have been put on the market by manufacturers, and some have proved very efficient.

The different types marketed up to August, 1925, are described in Bulletin 18, Methods and Costs of Rock-Dusting Bituminous Coal Mines.[41]

ROCK-DUSTING MACHINES FOR USE IN GASSY MINES

Various rock-dusting machines are being developed and have been greatly improved from experience gained in use. Present grave defects of many American machines are that they are driven electrically by motors that are not flame proof, and they can be operated only on trolley roadways, although with several kinds some dusting

[41] Owings, C. W., and Dodge, C. H., Methods and Costs of Rock-Dusting Bituminous Mines: Coal-Mining Investigations, under auspices of Carnegie Institute of Technology, United States Bureau of Mines, Advisory Board of Coal-Mine Operators and Engineers, Bull. 18, 1925, 192 pp. Published by Carnegie Institute of Technology.

can be done in parallel roadways by means of extension air hose of large size (2½ to 4 inches).

Trolley-operated rock-dusting machines can not be used in entries or in the rooms of gassy mines that are not ventilated by fresh intake air, the very places that are dangerous. One ignition of gas recently occurred which rock-dusting prevented from propagating in coal dust, but it killed one and burned the other of the two men handling the machine. Permissible rock-dusting machines are now available that can be operated from storage-battery locomotives and so are, with proper precautions, safe to use in a gassy mine.

ROCK-DUSTING ON SLOPE ROADS

On slope roads rock-dusting machines can be lowered or raised by rope. The blowers and feed devices on the machines could be actuated by chain drive from the wheels of the truck. A simpler way, however, would be to dump the rock dust at intervals, then use a V-shaped spreader with a rotary brush similar to that of a street sweeper. In the Dawson (N. Mex.) mines the dragging of small trees gave similar results.

ROCK-DUST BARRIERS

Rock-dust barriers were developed early at the experimental mine, where they started from the earliest form of Taffanel cross shelves. Those that proved successful in stopping large-scale coal-dust explosions are described and illustrated in Technical Paper 84 and Bulletin 167.[42] The latter gives the detailed results of the tests.

The factors of importance in the effective operation of barriers are as follows:

1. Inclosing the rock dust to keep it from becoming wet by the humidity of the mine air and from being contaminated by coal dust deposited by air currents.

2. A positive instantaneous means of discharging the rock dust by a rush of air stronger than one caused by normal mine operations.

3. Preventing the rock dust being discharged en masse, but insuring that it is thrown in a shower lasting several seconds, and that some is retained on opened hanging devices where it will be of effect in extinguishing flame if the barrier is dumped by a shock wave preceding the flame of a slow-moving explosion.

4. Enough rock dust to insure the extinguishing of the flame. When the flame of an explosion is extinguished, it will not reignite, and the pressure rapidly drops to one that is nondestructive. Tenta-

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[42] Rice, G. S., and Jones, L. M., Methods of Preventing and Limiting Explosions in Coal Mines: Tech. Paper 84, Bureau of Mines, 1915, 45 pp. Rice, G. S., Jones, L. M., Egy, W. L., and Greenwald, H. P., Coal-Dust Explosion Tests in the Experimental Mine, 1913 to 1918, Inclusive: Bull. 167, Bureau of Mines, 1922, 639 pp.

tively the bureau recommends, in general, that the contents of the barrier shall suffice to provide at least 100 pounds of rock dust per square foot of cross section of the passageway.

5. Placing the barrier (which may consist of individual boxes or troughs forming a unit), if possible, at a point where the entry or passageway is straight, without side openings, and not more than 12 feet wide or 9 feet high. To provide clearance for haulage and travel, the barrier should be at least as high above the rail as the lowest timbers or the roof.

6. Placing guards below the vanes to prevent accidental tripping by traffic. To protect men passing underneath, suitable guards or chains should prevent parts that swing downward from dropping too far if the barrier is accidentally tripped.

Some barriers that have been erected in mines will not meet these conditions; some that were tested by the bureau in its experimental mine failed because (1) they were not sensitive or quick enough in operation, (2) they dropped the load in a mass, (3) they did not hold enough rock dust, and (4) they were placed too close to the origin of a coal-dust explosion started by gas. In the near future the Bureau of Mines will officially test barriers submitted for approval

PURPOSES OF ROCK-DUST BARRIERS

Barriers are not a substitute for general rock-dusting; for example, they were tried by a company in its mines in Illinois and were reported to have stopped a large number of explosions that started between the barriers and the face or else between barriers. These explosions, however, killed a considerable number of miners and caused loss of property; in addition, there was always danger of an explosion passing a barrier or being so extensive that the poisonous gases (chiefly CO) of the afterdamp would kill large numbers of men. However, although barriers do not replace general dusting, they are exceedingly valuable when used in these ways:

1. As secondary defenses on main entries, thus sectionalizing the mine.
2. At the mouth of each branch entry and of each panel entry.
3. At the entrances of connections to adjacent mines.
4. In the return air courses of mines where a large amount of watering is done at the faces of rooms and headings, as in Utah, and the return air is humid. Under these conditions further protection against coal-dust explosions by barriers is advisable, particularly because the returns may carry some inflammable gas.

A high moisture content in the returns does not, however, obviate the desirability of general rock-dusting; for although the rock dust itself will become moist and will no longer rise as a dry-dust cloud, it so increases the ash content of the dust normally present that the mixed dust becomes nonexplosive. This result has been demonstrated by tests of rock dust plus water in the experimental mine.[43]

Moreover, the writer noted early in the large-scale tests that in moist places rock dust, because it absorbs water by capillary action, materially assists the wetting of coal dust. Coal dust alone is difficult to wet; it repels water, and when wetted it rapidly gives up the moisture to an air current of average humidity. Further, when rock dust is present the return air may be dryer for a time and yet the caked rock dust will mechanically hold most of the coal dust.

When barriers are erected in a return where the air is moist, it is manifest that the rock-dust contents to be of any value must be kept dry in covered waterproofed inclosures, such as those that were designed for the Bureau of Mines and passed tests successfully. For description see Bulletin 167 [44] or Technical Paper 84.[45]

ROCK-DUSTING VERSUS WATERING

Long wet sections in entries, especially where there is opportunity for the relief of pressure through side openings, may stop an explosion or a branch of it, but the favorable effect can not be relied upon. The writer has investigated an explosion that after it started strongly continued for several hundred feet through wet stretches, even those with water over the rails.

Coal dust from dry areas is swept along by an explosion and the pioneering air wave, which carries along timber, pieces of debris, and pieces of coal and makes dust by smashing the coal and by abrading the coal ribs. Rock-dusting neutralizes the explosibility of such newly made coal dust; watering does not. Where the entry is dry, the force of the advance air waves sweeps the coal dust into the air but also raises the rock dust. In the resulting dust cloud particles of rock dust are interposed between particles of coal dust; they absorb heat and act as a screen, preventing the transmission of heat from one coal-dust particle to another. It is granted that if coal dust is kept continuously so wet that it can not be raised by a strong blast of air the watering will be effective, but experience has shown that it is almost impossible to keep road dust wet enough except for a short time; strong ventilating currents dry the dust quickly.

A great advantage of a light-colored incombustible rock dust, like that of limestone, is that increasing proportions of combustible dust

[43] Rice, G. S., Jones, L. M., Egy, W. L., and Greenwald, H. P., Coal-Dust Explosion Tests in the Experimental Mine, 1913 to 1918, Inclusive: Bull. 167, Bureau of Mines, 1922, pp. 394–401.

[44] Rice, G. S., Jones, L. M., Egy, W. L., and Greenwald, H. P., Work cited, pp. 447–466.

[45] Rice, G. S., and Jones, L. M., Methods of Preventing and Limiting Explosions in Coal Mines: Tech. Paper 84, Bureau of Mines, pp. 24–27.

can be approximately judged. Estimates made in this way, however, should not supplant sampling and analysis. On the other hand, no one can determine by the eye whether moist coal dust is in such a condition that it will not be raised into the air and ignited, especially if some inflammable gas, which greatly increases the inflammability of coal dust suspended in air, is present.

SUMMARY OF FACTS REGARDING COAL-DUST EXPLOSIONS AND THEIR PREVENTION

1. Bituminous coal dust in air is explosive but its explosibility varies according to size, kind, volatile-combustible ratio, and amount of water and external incombustible present.

2. By the Bureau of Mines definition, which is based on tests, coal dust consists of particles fine enough to pass through a 20-mesh Tyler sieve (400 openings to 1 square inch); hence the maximum dust particle is about one thirty-third inch in diameter. This designation of coal dust refers to the initial stages of an explosion. As an explosion increases in temperature and violence, much coarser particles doubtless enter into it.

3. The finer the coal dust the more readily is it inflamed in air.

4. For determining the comparative hazard the Bureau of Mines rates the characteristic size of coal dust as the percentage of all the dust finer than 20 mesh that passes through a 200-mesh sieve.

5. The size and shape of coal-dust particles in different mines vary widely. In some mines the coal breaks into coarse cubic particles, and the average proportion of 200-mesh dust may be only 10 per cent. For softer coals the average proportion of 200-mesh dust may be 20 per cent. The dust of the more friable coals may average as high as 40 per cent through 200 mesh. For the same kind of coal this size is almost as sensitive as 90 per cent through 200 mesh, which is the standard pulverized dust that the bureau uses for explosion tests.

6. With other factors equal, the higher the ratio of volatile combustible to total combustible matter the more inflammable (more easily ignitible) is the dust; but relative inflammability is not by itself an index of the violence to be expected from a coal-dust explosion.

7. A dust in which the proportion of volatile combustible in the total combustible is 5 per cent or less, as it is in a true anthracite dust, has not been found to propagate an explosion.

8. The explosibility of coal dust is measured by the bureau in percentages of the total incombustible, including rock dust, in the dust mixture that prevents ignition or propagation.

9. Methane or fire damp in amounts less than the explosive limit (5 per cent) increase the inflammability of a coal dust in proportion to the percentage present.

10. For every per cent of methane 3 to 8 per cent of rock dust must be added to that required to prevent the ignition of dust or the propagation of an explosion in dust when no gas is present.

11. Watering prevents coal-dust explosions only when it wets the coal dust enough to prevent its being raised into the air by a blast or concussion.

12. Watering was tried for about 30 years, but it failed signally to prevent explosion disasters in any coal-mining country.

13. For keeping down dust, watering can be used to best advantage (1) on the cutter bars of machines, (2) in washing the coal face, and (3) in drenching sprays, at the entrance of partings or sidings, for washing down coal dust on cars.

14. For these purposes watering does not conflict with rock-dusting. If watering is used along trackways to prevent explosions, some rock-dusting may well be done; it will help in wetting the coal dust, for the latter naturally sheds water.

15. Rock-dusting is cheaper than watering that is thorough enough to be really effective.

16. To rock-dust effectively, first clean up all loose coal and dust in the passageway; then distribute the rock dust, preferably by blowing it so strongly onto ribs and timber as to dislodge and supplant float coal dust. If the rock dust is distributed in this way enough, or nearly enough, will fall on the floor. The first treatment will require 2 to 4 pounds per linear foot for an entry of ordinary width. In rooms the gobs as well as the roadways should be kept well rock-dusted.

17. The road dust and rib dust should be sampled and tested at regular intervals, and the percentage of incombustible matter they contain should be recorded. In every part of the average bituminous coal mine the incombustible should always be kept higher than 55 per cent and should average more than 65 per cent; these percentages include natural moisture, ash, and inert matter. In return airways that carry inflammable gas the percentage of incombustible matter should be raised 1 to 2 per cent for each 0.25 per cent of gas present.

18. Some coal-mining men think that their mines are not subject to coal-dust explosions because an explosion has never occurred therein or in the mining district. To start and to propagate a coal-dust explosion takes an unusual combination of circumstances. The chances may be small so long as a mine is kept in good condition, but the mine management that does not follow a specific method of

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preventing explosions is shouldering a serious moral and financial responsibility.

19. Different mining districts have widely different explosion hazards, but the methods of sampling and testing used by the bureau for each mine and its dust determine whether the hazard is slight; if it is, the cost of obtaining virtual immunity from coal-dust explosions will also be slight; for the less inflammable the natural dusts of a mine the less rock-dusting will be needed.

COAL-DUST EXPLOSIONS IN TIPPLES AND SHAFTS

During the past few years many managers of large new mines have introduced skips for hoisting coal, following the practice at iron and copper mines. Skips cause some undesirable production of coal dust in the dumping of coal underground; unless special provisions are made, this coal dust is carried into the mine if the shaft is intaking and up the shaft if it is upcasting. In some mines the ventilation of the shaft is made neutral or nearly so. In either upcasting or neutral shafts the float dust tends to accumulate on horizontal timbers or shaft sets.

A severe explosion at one mine is thought to have been caused by an open electric switch in the screen room of the tipple; the explosion traveled down the dry skip-hoisting shaft. At a mine like this rock dust evidently could not be applied in the screen room or used in the underground tipping station, for it would damage the commercial value of the coal if used extensively enough to prevent explosions. However, rock dust could be used to advantage in shafts with timber sets and other places for dust to lodge, as it would displace coal dust and if dry would make any coal-dust cloud less inflammable. The use of water, except in an upcast shaft or as a fine spray at the underground tipple, would be out of question. Too much water would make the coal stick in the chutes and skips.

To formulate any rules generally applicable for minimizing coal dust at mines using skips is difficult, as the practice of underground dumping has not been standardized; in general, however, rotating cylindrical dumps, fitting closely into the sides of inclosed chutes or bins, would minimize the amount of dust entering the air. If there were room in the shaft, an exhaust pipe, 12 inches in diameter, from the inclosed bin at the bottom might be run to the surface and thence to a fan and a dust collector. At one skip mine a rock-dusting bin above the inclosed bin into which the mine cars dump liberates mechanically a certain amount of rock dust into the air current entering the mine. This float rock dust tends to neutralize float coal dust escaping from the underground dump.

In the screen and tipple room on the surface the screens and tipples should have exhaust hoods with pipes rhnning to fan and dust collector.

The most important requirements for dusty places at the bottom or top of a shaft are to exclude sources of ignition, such as open electric switches and open lights, and to prohibit smoking or the carrying of matches. Inclosed or permissible junction boxes, approved wiring and motors, permissible miners' lights, or permissible inclosed fixed electric lights should be employed.

Motors used for many purposes in and about mines have not been submitted as yet to the Bureau of Mines for tests to determine their permissibility.

Motors tightly inclosed to prevent access of coal dust and ventilated by special air pipes from outside the building (to create an internal air pressure) have been used in pulverized fuel plants; they could be used for motors in coal-screening rooms and pneumatic coal-cleaning plants and would greatly increase safety by preventing the ignition of coal dust by electric sparks or shorts in the motors.

IGNITION OF GAS OR BITUMINOUS COAL DUST BY EXPLOSIVES

Bureau of Mines records show that 35 per cent of the major explosions of gas and bituminous coal dust in the past have been caused by nonpermissible explosives, such as black blasting powder and dynamite. These explosives have also caused a much larger proportion of the minor explosions (those that cost less than five lives), which include shot-firers' explosions, so called because they happen when only the shot firers are in the mine. Where coal is shot off the solid with nonpermissible explosives, and the shot firer either does not know what is in the shot he is firing or does not have time to charge and stem the hole properly, the combination is triply hazardous.

Recently two shot firers who had charged and fired 85 shots in 35 minutes were caught by an explosion from the last shot just before they were to be hoisted out of the slope. If it had occurred when a full shift was in the mine, the explosion would have killed every man.

When the Federal Government began its investigations of coal-mine explosions in 1908, the proportion of explosion disasters caused by explosives was much larger than now. The first important work undertaken was to increase the use of safe explosives, as virtually no so-called " safety " explosives were being made then. The few types that were made were later withdrawn from sale, but they did represent an advance in principle. As soon as a testing gallery was erected at Pittsburgh a schedule of tests was formulated, and early in 1909 manufacturers began submitting explosives.

The manufacture and use of permissible explosives grew slowly at first but has increased steadily. In spite of the danger of the nonpermissible explosives, however, the total amount of permissibles used is only one-fourth of that of all explosives used in coal mines.[45a] Fortunately, permissibles are used most extensively in the mines that are naturally most dangerous, but the record of explosions and mine fires caused by nonpermissibles demonstrates the necessity of substituting permissible explosives.

The Bureau of Mines, after long and careful inquiry and consideration, made the following decision as to its policy on blasting in coal mines:

> In the interest of safety the Bureau of Mines recommends that for blasting in coal mines permissible explosives, fired electrically, be exclusively used; and that, as an aid to blasting, all coal which is feasible to cut should be cut or sheared.

In issuing this statement of policy, January 26, 1925, the bureau stated:

> Permissible explosives are devised to reduce the hazard of igniting gas and coal dust. They have been in use in the United States since 1909, and the amount used annually has increased from less than 9,000,000 pounds in that year to more than 50,000,000 pounds in 1924.
>
> Sixty-five of the explosion disasters in American mines from 1908 to the early part of 1923 were definitely found to have been caused through the ignition of gas and dust by explosives. The total number of men killed in these 65 explosions was 758. All of these 65 mine explosions were found to be due to the use of nonpermissible explosives.
>
> There is unquestioned evidence that undercut or overcut coal can be blasted by permissibles as cheaply as by nonpermissible explosives. Under other conditions (that is, "blasting off the solid"), where the direct cost of using permissibles may be greater, the indirect savings offset this, when the cost of compensation for killed or injured workmen, of interruption to work, and of damage to property from explosions or fires caused by nonpermissible explosives are taken into consideration.

The bureau recognized that the change from nonpermissible to permissible explosives would be important to the industry and would have to be gradual. The fields where the change should be made first were plainly indicated as those in which gas or dust explosions have occurred from time to time.

WHAT ARE PERMISSIBLE EXPLOSIVES?

Permissible explosives are those having a flame that is comparatively short in length and duration. All as yet devised and used are of the detonating type and are ignited by a detonator which for safety should be an electric one.

[45a] 29 per cent of explosives used in bituminous and 31 per cent of those used in anthracite mines were permissibles in October, 1927.

SPECIFICATIONS FOR A PERMISSIBLE EXPLOSIVE

A permissible explosive is an explosive which is similar in all respects to the sample which has passed certain tests prescribed by the Bureau of Mines to determine its safety for use in coal mines and when used in accordance with the conditions prescribed by the Bureau.[46]

Permissible explosives are designed especially to prevent ignition of gas or of coal dust by blasting in coal mines. Not only should they be used for "shooting" coal but also for shooting down top, lifting bottom, and driving crosscuts or tunnels in rock where inflammable gas is liable to be given off. Special classes of permissible explosives with higher rates of detonation are ordinarily used for rock work.

CONDITIONS PRESCRIBED FOR USE OF PERMISSIBLE EXPLOSIVES [47]

1. That the explosive is in all respects similar to the sample submitted by the manufacturer for test.
2. That electric detonators are used of not less efficiency than those prescribed; namely, those consisting by weight of 80 parts of mercury fulminate and 20 parts of potassium chlorate (or their equivalents).
3. That the explosive, if frozen, shall be thoroughly thawed in a safe and suitable manner before use.
4. That the quantity used for a shot does not exceed 1½ pounds (680 grams) and that it is properly confined with clay or other incombustible stemming.

CONDITIONS UNDER WHICH A PERMISSIBLE EXPLOSIVE SHOULD NOT BE USED

After an explosive has passed the required tests and its brand name has been published in a list of permissible explosives it is not used in a permissible manner if one or more of the following conditions prevail:

1. If stored under improper conditions until it undergoes a change in character.
2. If used in a frozen or partly frozen condition.
3. If used in excess of 1½ pounds (680 grams) per shot.
4. If the diameter of the cartridge is less than that designated in the column "smallest permissible diameter."
5. If fired with an electric detonator of less efficiency than that prescribed.
6. If fired with fuze.
7. If fired without stemming.
8. If fired with combustible stemming.
9. If fired in the presence of a dangerous percentage of fire damp.
10. If the shot is a depending shot or is bored more or less straight into the solid coal or has a burden so heavy that the shot obviously is liable to blow out.

In appearance and general characteristics permissible explosives are not unlike dynamite and are similarly fired by electric detona-

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[46] Procedure for Testing Explosives for Permissibility for Use in Coal Mines: Sched. 17A, Bureau of Mines, 1926, 11 pp.

[47] See footnote 46.

tors; fuze and cap may be used, but are not now approved by the bureau, as an open flame is needed to light the fuze, and the fuze itself ignites gas.

Permissible explosives, unlike dynamite, are compounded and prepared so that certain damping ingredients shorten the flame and lower its temperature. Permissibles are classed by the bureau according to their principal explosive ingredient, as follows:

Class 1.—Ammonium nitrate explosives.

Class 2.—Hydrated explosives like low-grade dynamite, except that one or more of the salts contains water of crystallization.

Class 3.—Organic nitrate explosives, including nitrostarch.

Class 4.—Nitroglycerin explosives. These contain free water or an excess of carbon, and some contain salts to reduce the strength and the shattering effect.

Class 5.—Ammonium perchlorate explosives.

Permissible explosives are far safer to use in the presence of gas or dust than any nonpermissible explosives, but are by no means absolutely safe. They should not be fired where gas is present in sufficient proportion (2 per cent) to be detected by an approved safety lamp, except under special conditions and precautions.

RECOMMENDATIONS ON PREVENTING IGNITION OF GAS OR COAL DUST

1. In coal mines neither permissible explosives nor other explosives should be fired simultaneously in two or more holes, one or more of which is " dependent " on the proper working of another.

2. The best practice is to fire only one shot at a time, unless shot firing is done electrically from the surface and all men are out of the mine, as is the practice in some mines in Utah and in Colorado.

3. Under the best practice the firing of shots is done only by certified fire bosses, who charge and tamp each shot and examine for gas before and after firing.

4. An even safer practice is for these fire bosses to charge, tamp, and fire the shots when all other men are out of the mine.

5. For shot firers to fire shots of black blasting powder or dynamite in rapid succession is bad practice and will certainly cause explosions sooner or later, especially if such shots are " on the solid." The death rate among shot firers in certain fields is appalling; their work is almost suicidal. In the long run the operator also has to pay heavily through the property destroyed by explosions or by mine fires.

6. Not more than the day's supply of explosives should be sent underground in any day. Any excess should be returned to the surface or else placed in a special magazine.

7. The best method of transporting explosives [48] from local magazines is in sacks carried by shot-firing foremen; an alternative is to transport them in insulated and covered special cars. Sacks used for transporting explosives should be treated so as to be noninflammable.

8. Detonators should never be carried in the same sack with explosives but in special containers properly padded, as in a leather pocket hung by a strap over the shoulder and made of nonconducting material.

9. Shots should be fired by "permissible" single-shot shot-firing units [49] and not from a trolley wire or power line or from any battery likely to give a weak current that may cause a misfire.

10. If a misfire occurs during electric shot firing, no one should go to the blast hole for at least five minutes,[50] preferably much longer for safety, as the explosives may be imperfectly detonated and be burning. If a misfire occurs when fuze is used, do not return for at least one hour.

11. If a shot has misfired, the stemming should be washed out and the charge carefully removed. Regulations in some States require that a parallel hole should be used; under such conditions, the parallel hole should be drilled about 2 feet distant, loaded, and fired, but only after the vicinity has been carefully washed down with hose for 11 yards from the hole or has been rock-dusted.

12. Mud-capped (adobe) shots are vicious in a coal mine; they have caused coal-dust explosions. To blast a large rock that can not be broken by sledge, use a small block hole and a permissible explosive, properly stemmed.

13. Air-spacing, by putting a small-diameter cartridge in a large-diameter hole with clay stemming tamped to the mouth of the hole, reduces the shattering effect.[51]

14. A method of cushioned blasting that has been tried leaves a space between the cartridge and the stemming, but results of preliminary tests by the Bureau of Mines are against the safety of this method.

15. In another method which has been much tried in Germany and in this country paper tubes filled with loose rock dust are put in the drill hole in place of clay stemming. When the shot goes off the loose stemming is compacted, giving the effect of air spacing. It is claimed that (*a*) if the shot blows out the rock dust is ejected and

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[48] Ilsley, L. C., The Transportation of Explosives in and about Mines: Repts. of Investigations, Serial 2528, Bureau of Mines, September, 1923.

[49] Crawshaw, J. E., Ilsley, L. C., Parker, D. J., and Fieldner, A. C., Permissible Explosives, Mining Equipment, and Rescue Apparatus Approved Prior to Jan. 1, 1925: Tech. Paper 376, Bureau of Mines, 1925, p. 24.

[50] Hall, Clarence, Permissible Explosives Tested Prior to Jan. 1, 1911, and Precautions To Be Taken in Their Use: Miners' Circ. 2, Bureau of Mines, 1911, p. 11.

[51] Hall, Clarence, and Howell, S. P., Tests of Permissible Explosives: Bull. 66, Bureau of Mines, 1913, p. 21.

probably will, by its absorption of heat and consequent cooling effect, prevent ignition of coal dust and possibly of methane; (*b*) if a misfire happens, it is comparatively safe to pull out the loose stemmining and the primer (the cartridge containing the detonator).

16. Although the use of loose rock dust in place of clay stemming, with an air space between the cartridge and stemming, proved successful in the production of a larger percentage of lump coal, as yet the bureau has not tested it extensively enough to determine whether it is as safe as tight clay stemming.

17. The use of rock dust on a small shelf or holding device at the mouth of the hole was proposed by Watteyne, of Belgium, about 1912. This precaution is unquestionably good.

18. Whenever a shot is of such character that in spite of care the surrounding conditions present hazards, rock dust should be distributed abundantly in the vicinity of the shot or the face washed down thoroughly within 10 yards of the shot.

19. The "bug dust" should be removed from the undercutting and either loaded out or placed where it will be harmless and either wetted or covered with rock dust before shooting.

20. In electrically equipped mines in which the tracks are used for the return or "negative" current it is highly important that the bonding of the track and the grounding be well done to prevent stray currents reaching the working places, causing premature firing of shots.

ELECTRIC SHOT FIRING FROM SURFACE

The large number of explosion disasters and shot-firers' explosions in coal mines before "permissible" explosives were manufactured or extensively used led to the introduction of the system of electric shot firing from the surface, when everyone had come out of the mine.[52] This system was first employed in Utah mines and subsequently in Colorado, New Mexico, Oklahoma, Kansas, and Alabama. It did not avoid explosions, some of which were very violent and damaging to property but killed no one.

However, some complications attend the use of the system, such as difficulties in maintaining wiring and the failure of a certain proportion of shots (usually 1 to 5 per cent) to detonate, the percentage depending on the care with which the shot-firing wires are installed and maintained. Also, there have been a number of instances of local premature shot firing, with resultant accidents, caused by stray currents.

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[52] Rice, G. S., and Clark, H. H., "Shot firing in coal mines by electric circuit from the surface"; Trans. Am. Inst. Min. Eng., vol. 50, 1914, p. 723. Clark, H. H., Breth, N. V., and Means, C. M., Shot Firing in Coal Mines by Electricity Controlled from Outside: Tech. Paper 108, Bureau of Mines, 1915, 36 pp.

In addition, before mining practice was corrected by leaving a long gap (closed by a flexible cable when all was ready) in the shot-firing circuit while men were in the mine, lightning sometimes entered from the surface, jumped ordinary switches, and aroused fear that shots would be fired prematurely. Moreover, if strong power was left on for a few seconds or the shot-firing switch was closed a second time, short circuits between loose lead wires sometimes ignited gas or dust. The latter danger was obviated by using a mechanical shot-firing switch which remained closed a second or two and could not again be operated.

As the method of shot firing from the surface developed and increasing precautions were observed, less and less trouble was noted. Wider use of permissible explosives, however, gradually led to the abandonment of the method, except as employed in the Rocky Mountain States by a few companies that had systematized the procedure and considered it the safest plan of shot firing for mines in which conditions were naturally hazardous because of dust or gas.

EXPLOSIVES ACCIDENTS OTHER THAN THOSE CAUSING IGNITION OF GAS OR DUST

Table 4 (p. 6) shows that accidents from explosives, except those involving the ignition of gas or coal dust, have been numerous. During the eight years from 1917 to 1924 the annual number of deaths from such accidents (not including coal-dust and gas explosions) ranged from 206 in 1919 to 92 in 1922. The abnormally high number for 1919 was due to 92 men being killed by the explosion of a car of black blasting powder in a man trip in an anthracite mine.

Table 4 also indicates that the largest number of deaths through the use of explosives is from premature shots, which cause 32 to 57 deaths yearly. These fatalities are considered largely preventable because, for the most part, they are due to the use of fuze that is cut too short. Another large group of explosives accidents is easily preventable—those due to men returning too soon after blasting. Delayed shots are especially likely to occur when damaged fuze is used. Electric shot firing avoids the hazards of fuze, and the Bureau of Mines considers it of vital importance in the use of permissible explosives. Another group of accidents caused by carelessness is that attributed to premature firing while holes are being charged. The use of an iron tamping bar that struck a spark from a sulphur ball or a rock parting has caused many of these accidents. Undue pressure or ramming when a cartridge jams in the hole is another cause.

Bad practice in the transportation of explosives, especially in the haulage of black powder in cars drawn by trolley locomotives, has caused many accidents, as when the kegs have come in contact with the trolley wire or there has been grounding through the wheels and drawbars of the cars. Some of these ignitions have been due to sparks produced at points where the flow of current through the metal containers was interrupted, as at a stopper or at a joint, and some have been due to sparks from the trolley wheel setting fire to loose grains of the black powder. Permissible explosives are much less likely to be ignited in this manner; in fact, no similar explosions attending their transportation have ever been reported to the bureau. Nevertheless, it is unwise to haul even permissible explosives by trolley unless they are in a covered wooden-body car with no metal exposed on the inside.

In general, one can say positively that the observance of well-known precautions will prevent at least one-half of the accidents from explosives.

SUMMARIZED RECOMMENDATIONS ON THE TRANSPORTATION, STORAGE, AND USE OF EXPLOSIVES IN COAL MINES

1. Only permissible explosives should be used. Of these there are many varieties, suitable for different purposes—some for blasting friable coal, some for strong or tough coal, and others with brisant or shattering effects for blasting rock, as in "brushing" or "lifting bottom."

2. Permissibles for the mine should be bought in such quantity that any one lot will not be stored in the surface magazine more than two months, preferably less than one month, as they tend to deteriorate through long storage.

3. The magazine should be appropriately situated, with regard to the recommendations made by the Bureau of Mines.[53]

4. Only sufficient explosive for one day's use should be sent into the mine, and it should be taken in either in sacks carried by foremen or in special insulated magazine cars having an inner wooden lining and no nails, screws, or bolts exposed on the inner surface; the cars should have covers similarly constructed.

5. Black blasting powder in metal kegs, carried in open cars drawn by trolley locomotives, has caused some disastrous explosions. The laws of certain States forbid this method of transportation.

6. Miners carrying blasting-powder containers of metal should not be allowed to ride on trolley-locomotive trips, as contact with the irons or bolts of the car body has caused ignition of the powder.

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[53] Munroe, C. E., and Hall, Clarence, A Primer on Explosives for Coal Mines: Bull. 17, Bureau of Mines, 1911, 69 pp.

Hall, Clarence, and Howell, S. P., Magazines and Thaw Houses for Explosives: Tech. Paper 18, Bureau of Mines, 1912, 34 pp.

7. Detonators should not be carried in the same sack or car with explosives of any kind.

8. Detonators should be carried in wooden containers with recesses or in a padded haversack and not in contact with one another.

9. If underground magazines are used in a large mine, there should be stored in any one magazine only enough to serve that section of the mine for one day. Such a magazine should be recessed, whitewashed, and have stout doors of wood or concrete. It should be in a dry place where the roof is strong or else is supported by arching or by I beams. The vicinity of the magazine should be heavily rock-dusted.

10. Detonators should not be kept in the magazine for permissible explosives but in a separate small magazine with a door. This small magazine should be at least 50 feet away from the other.

11. Underground magazines should be used only when they are in charge of authorized foremen or shot firers who carry the explosives to the different working places and charge and fire the hole—a system used by some of the largest and best-organized mining companies in this country.

12. Where the shots are charged and fired by the individual miner, he must have a box for explosives in which nothing else will be put. Only a day's supply should be carried, and the box should be kept locked. The box should be placed in a recess or crosscut, where it will not be endangered by flying pieces from blasts or by haulage.

13. Detonators should be kept in another box 25 feet distant or in a hole or recess in the rib.

14. Drill holes should be placed with great care. It is safer and breaks less coal to use a number of carefully placed holes with light charges much smaller than the charge limit (1½ pounds) than to attempt to shoot a face with only two or three heavy charges.

15. The bureau recommends that coal be cut or sheared before blasting and that permissible explosives be used exclusively in coal mines. Blasting coal "off the solid" with black powder or dynamite is dangerous.

16. Holes should not extend to within a few inches of a plane at right angles to the back of the cut or shear.

17. Where the coal is thick, 5 feet or more, and is strong, "snubbing" shots or special cutting should be used to relieve the breaking shots.

18. No holes should be drilled which at the back will strike the roof; they should be kept 6 inches below the roof, lest the shots crack or weaken it.

19. Rib holes should not "grip" into the rib; in other words, should not touch the plane of the rib extended.

20. In charging holes a man should always remember that the limit of weight of permissible explosives is 1½ pounds in any one charge. As the explosives are ordinarily put up by manufacturers, this means three to five sticks. The weight limit of 1½ pounds should never be exceeded and the amount of explosives should be reduced to that quantity which experience shows will just break up the coal but will not throw it from the face.

21. The borehole should be cleaned out carefully with a scraper. The cartridge should be pushed to the back of the hole with a wooden bar after the electric detonator has been put in the outer end of the last cartridge, in accordance with directions given in Bureau of Mines Bulletin 17. The cartridges should all be pushed in at the same time to avoid particles becoming lodged between them, a frequent happening when cartridges are pushed back one at a time.

22. Until it is time to connect the legs of an electric detonator with the lead wires the legs should be kept twisted together to prevent premature firing by stray currents. In twisting a leg onto a lead wire care should be taken that the other leg does not fall on a rail or pipe carrying a stray current or against an electric machine, the frame of which might be charged with enough current to fire a detonator and thus cause a bad accident.

23. The hole should be stemmed with clay to its mouth. If suitable clay is not available in the working places, the mine operator should send loads of it to points conveniently near. Only hardwood sticks should be used for tamping. Iron or copper-tipped bars should never be used for that purpose.

24. Firing only one shot at a time is the best practice. Depending shots, those depending for effectiveness upon the success of the previous shot, should never be fired.

25. The best practice is to have all shots charged, stemmed, and fired by careful officials who have State certificates as foremen or fire bosses. If one of these officials does not charge, stem, and tamp the hole himself, the work should be done under his immediate direction.

26. In gassy mines a test should be made with an approved flame safety lamp or a gas detector before a shot is fired and another test made a suitable interval after a shot is fired.

27. If a shot fails to go off when electric detonators are used, men should wait at least 10 minutes before returning to the place. The bureau does not approve of fuze as a means of firing explosives in coal mines, but if fuze is used and a shot fails to go off the shot firer and miners should wait at least one hour before entering the place.

28. Only "permissible" "single-shot blasting units," tested and approved by the Bureau of Mines, should be used for shot-firing, except when shots are fired electrically from the surface and all the men are out of the mine. Improvised batteries, usually without protective devices that require at least two actions for firing, are liable to fire shots prematurely.

29. Firing shots from power lines in gassy mines is particularly dangerous, inasmuch as an electric spark after the shot may ignite gas. In electric shot firing from the surface it is therefore important to put on the power but once and for a momentary contact only by a mechanically controlled switch.

MINE LIGHTS AS A CAUSE OF EXPLOSIONS

In the early days of coal mining candle flames were used to detect the presence of fire damp or black damp and ignitions of fire damp were frequent. Friction sparks from an iron on a stone wheel, which ordinarily will not ignite methane, were used to some extent in gassy mines, but generally at that period the practice was to "burn out" the gas in the mine by fire runners before the other men went in. Within the past 30 years it was quite customary in coal mines not rated as gassy for miners to burn out the gas in overhead cavities before too much accumulated, although the method was very dangerous. Many of the early explosion disasters were doubtless caused in this manner, and up to the present time many accidents from fire-damp burnings and explosions have been caused in what are called nongassy mines by the use of matches or open lights.

SAFETY LAMPS[53a]

In 1815 Sir Humphry Davy invented his famous safety lamp for gassy mines. Other designs quickly followed, but with modifications the "Davy" still persists in one mining district in the United States. In a rapid current of air the flame will pass through the gauze of a Davy lamp and ignite gas outside. Hence, as larger mines required stronger and more rapid ventilation currents, improved safety lamps became necessary. The Davy has been condemned by the testing stations of every coal-mining country.

PERMISSIBLE FLAME SAFETY LAMPS

Modern flame safety lamps, such as those tested and approved by the Bureau of Mines, have bonnets and double gauze and are magnetically locked.[54] Instead of having a gauze completely around the

[53a] See also p. 15.

[54] Paul, J. W., Ilsley, L. C., and Gleim, E. J., Flame Safety Lamps: Bull. 227, Bureau of Mines, 1924, 212 pp.

flame, as in the original Davy, these lamps have a glass cylinder which permits much better light; the gauzes rest on it. The lamps are magnetically locked, to prevent their being opened underground.

For the latest list of approved lamps see the special circular of information published every six months by the Bureau of Mines.

EXPLOSIONS CAUSED THROUGH IGNITION OF GAS BY OPEN LIGHTS

Open lights have caused 45 per cent of the mine-explosion disasters since 1910 by igniting gas and possibly, in some instances, directly igniting coal dust. Coal dust in surface plants has frequently been ignited by open lights or flame.[55] Also many men have been terribly injured by the burning and explosive inflammation ot fire damp ignited by open lights. Flame "safety" lamps that are key locked should be classed as open lights because they can be readily opened in a mine. At least 10 of the great explosion disasters and many lesser explosions have been caused by safety lamps opened for relighting. Many fires, some of which have caused explosions, have been started by open lights.

MINERS' PERMISSIBLE ELECTRIC LAMPS

Electric storage-battery lamps came into use in Europe about 25 years ago. They were followed 10 years later in this country by storage-battery cap lamps. In the past 10 years miners' portable storage-battery electric lamps have been constantly improved. Cap lights have been almost exclusively favored in the mines in this country, in contrast with the European practice of using hand lamps, which are much heavier but can be hung up or set on the ground in working places. To stand a lamp on the ground has certain advantages in thin coal, mined longwall, but is not favored in this country.

Several types of cap electric lamps have met the bureau's specifications for safety, for intensity and uniformity of distribution of illumination, and for durability. Their use has extended until in 1926 there were probably 235,000 or more in use. There are also about 65,000 flame safety lamps, the majority of which are used for testing.

BUREAU OF MINES POLICY REGARDING MINERS' LAMPS

In consequence of the dangers of open lights causing explosions or fires, the mine safety board of the Bureau of Mines, after careful and prolonged study of the question, rendered a decision thereon which was approved by the director May 8, 1926, and was issued

[55] Tracy, L. D., Explosion Hazards from the Use of Pulverized Coal at Industrial Plants: Bull. 242, Bureau of Mines, 1925, 103 pp.

lights other than permissible lamps should be used in and within 50 feet of it.

Fixed incandescent lamps should not be installed unless they are specially protected and are approved by the State inspection department.

If the fan is electrically driven, electric circuits should be planned with great care, and when the fan has been stopped for repairs, or for any other purpose, current should not be turned on until inspection has determined that less than 3 per cent of methane is present in the vicinity of the fan motor and controlling appliances.

ELECTRICAL MACHINERY

Efficiency in transmission and flexibility of application caused a steady increase in the use of electricity in mines during the past 30 years. To-day, except for rope haulage in dip mines, gathering of coal at the face by mules, and a very small use of steam for pumps in old mines and of compressed air for old mining machines and some for machines in gassy mines, probably 95 per cent of the mechanical power used in coal mines is electrical. If not safeguarded every electrical machine and its wiring can ignite gas and bituminous coal dust. Electrical installations may be classed as follows:

1. Stationary or fixed electrical installations: Main power and lighting circuits, transformers, charging stations for storage batteries, main (underground) slope hoists, main booster fans, compressors in gassy mines (limited use), main pumps, and car hoists in main bottoms. The foregoing require the services of attendants.

2. Portable electrical machinery with attendants: Trolley locomotives, cable-reel locomotives, storage-battery locomotives, storage batteries for mining machines, rock-dusting machines, small hoists, undercutting and shearing machines, drills, shoveling machines, loading machines, and some types of face conveyors. The foregoing types of equipment require attendants to see that they function properly, and except the storage-battery trucks and locomotives should have approved trailing cables, with proper connections, preferably approved explosion-proof junction boxes, in pure intake air.

3. Portable electrical machinery without attendants: Small electric pumps, portable compressors, and small electrically driven blowers and conveyors (without attendants), intended for use at the face, have temporary power lines and no attendants. Classes 1 and 2, installations and machinery that have attendants while in operation, provide opportunity for frequent inspection for inflammable gas and for stopping the machinery immediately if there are indications of

danger. Class 3, machinery that operates more or less regularly without attendants and with infrequent inspection, presents grave ignition hazards when used in the faces or returns of gassy mines.

ELECTRIC POWER LINES IN GASSY MINES

In laying out the electric circuits in gassy mines great care must be taken to keep nonexplosion-proof switches and power lines (other than approved trailing cables) out of the return air and also out of working places into which gas from the strata may enter suddenly. Unless this is done, the gain in safety through the use of permissible electric machinery is largely lost.

The fixed-power circuits in gassy mines always should be kept on fresh intake air and not nearer the face than any open crosscut, and only approved cables should be used in working places and in return air to connect "permissible" machinery with power lines. It is also advisable to make the connection with the power lines by means of "permissible" junction boxes rather than by exposed switches.

The reason for this precaution is that in or near the working places of a gassy mine the ventilating current is likely to be interrupted if a ventilating door is left open or a stopping or a line brattice is knocked down by a fall of roof or by the concussion of a shot or blast.

Roof falls may happen any time, and the danger is greater in working places. Such a fall may break down power lines, notably temporary wiring which may cause an arc by coming in contact with a rail or another wire. If the return airway is carrying gas in explosive proportions, an explosion may result.

PORTABLE STORAGE BATTERIES FOR MINING MACHINERY

A practice that greatly reduces the danger from explosions, and also is said to be economical in level haulage because it avoids wiring and bonding, is to use a "permissible" storage-battery truck for each mining machine, and thus do away with all wires in face or panel workings.

Use of this truck and of "permissible" storage-battery locomotives in coal mines tends to eliminate peak loads, thus permitting smaller generator plants to be used or, if power is purchased, the procuring of power at lower cost.

A few gassy mines have complete installations of permissible storage-battery equipment, thus eliminating all wiring underground and all bonding of track, and virtually preventing any possibility of electric ignition of gas or dust, accidents from electric shocks, pre-

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mature firing of explosives by stray currents, and mine fires due to "shorting."

ELECTRIC CIRCUITS IN COAL MINES[56]

CIRCUITS LEADING UNDERGROUND

Shafts, installation of circuits in.—(*a*) All power conductors installed in shafts shall be covered with approved insulating material throughout or guarded in an approved manner. They shall be securely fastened in such a way as to properly support the conductor. Conductors used as returns in shafts for ground-return systems shall be supported on insulators but need not be covered with insulation.

(*b*) Shaft cables that are so constructed that the whole or any part of the cable is not self-sustaining shall be supported in an approved manner at such intervals as may be necessary to prevent the occurrence of undue strains in sheath, insulation, or conductors.

(*c*) Shaft cables shall be so placed or protected that they are not liable to injury from falling material.

Boreholes, installation of circuits in.—(*a*) All conductors passing underground through boreholes shall be installed in an approved manner that shall prevent the occurrence of undue strains in sheath, insulation, or conductors.

(*b*) Telephone or signal wires shall not be installed in the same borehole with power wires unless either the signal or the power conductors in the boreholes are incased in metallic coverings that are effectively grounded.

Drifts or slopes, installation of circuits in.—Conductors of power circuits in drifts or slopes not exceeding 600 volts may be installed bare but shall be carried on suitable insulators securely fastened to the sides or roof of the entry. If the drift or slope is used for traveling, the conductors shall be guarded.

UNDERGROUND POWER, LIGHTING, AND MISCELLANEOUS CIRCUITS

Trolley wires.—(*a*) Trolley wires shall be of hard-drawn copper not smaller in size than No. 00 A. W. G. and shall be securely supported on approved hangers.

(*b*) Trolley wires shall be placed 6 inches outside of the rail, kept in as straight a line as practicable, and installed on the side of the entry opposite from shelter holes or traveling way or space. The height of trolley wires above the top of the rail shall be made as uniform as possible.

(*c*) On straight runs the hangers shall be placed not more than 20 feet apart, where the height of the roof above the track is 5 feet or less, and not more than 30 feet when the height is more than 5 feet above the track. In any event, the sag of wire between any two adjacent hangers shall not exceed 3 inches. On curves the hangers shall be placed so close together that the trolley wire at any one hanger may be entirely disconnected without exposing the locomotive runner to danger of contact.

(*d*) Sectionalizing switches shall be placed in the underground trolley wires and their feeders at intervals not exceeding 2,500 feet. These switches shall be arranged so they can be locked open.

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[56] Extracted from Safety Rules for Installing and Using Electrical Equipment in Coal Mines as Approved by the American Engineering Standards Committee, published by the Bureau of Mines as Tech. Paper 402. (Bureau of Mines and American Mining Congress, sponsors.)

(*e*) All branch trolley lines (wires) shall be provided with a (circuit) frog at the point where they leave the main and also with a (circuit) switch installed at or near the frog, by which the branch can be (electrically) disconnected from the main.

(*f*) Trolley wires that are less than 6½ feet above the top of the rail shall be guarded (by side boards or equivalents) at the points where men are daily required to work or pass under them.

Track bonds.—The tracks of all main haulage systems that use a rail return shall be bonded at every rail joint, and cross bonding shall be made for bonding around all (track) switches, frogs, or openings in the track so as to insure continuous return.

Power conductors.—(*a*) All power conductors transmitting current not exceeding 600 volts and paralleling a trolley wire shall be installed at least 6 inches from the trolley wire and on the nearest rib side of it and shall be supported on insulators of an approved type. When the height of the wire (above the floor) does not exceed 5 feet the insulators shall be placed not more than 20 feet apart and as much closer as necessary to support the wires properly. If the height of the wire is more than 5 feet the insulators shall be placed not more than 30 feet apart and as much closer as may be necessary to support the line properly.

(*b*) Sectionalizing (electrical) switches shall be placed at intervals not exceeding 2,500 feet in all underground feeder circuits operating at not more than 600 volts. When two or more sectionalizing switches are used for the same section of a mine, they shall be installed as close together as is feasible. All sectionalizing switches shall be arranged so that they can be locked in the open position.

(*c*) The negative or return wire of grounded mining machine circuits shall be afforded the same support and insulation as the positive or live wire.

(*d*) Bare electric-power conductors shall not be installed in any sections of the mine not regularly inspected. Power conductors may be permitted in such sections of the mine if they are so installed and guarded, as by placing in pipes or trenches, that they can not be damaged by falls of rock or coal or by other disturbances that might occur in places not regularly inspected.[57]

Branch circuits.—(*a*) Branch circuits shall be installed and maintained in the same manner as main conductors.

(*b*) At a point where a branch circuit leaves the main circuit there shall be placed a switch that will cut off all current from the branch circuit.

(*c*) The conductors of branch circuits for operating mining machines shall be not smaller than No. 4 A. W. G. copper wire. The conductors of pump circuits shall be not smaller than No. 8 A. W. G.

(*d*) Entries or passageways in which wires are installed must be kept sufficiently free from rock, slate, or other material to permit ready access to the wires at all times.

Room wiring.—(*a*) Rooms where permissible equipment is required shall not be wired. This shall not prevent running approved trailing cable into the rooms for the purpose of operating permissible equipment.

(*b*) Where room wiring is approved it shall be considered and installed as branch circuits.

Lighting circuits.—(*a*) Lighting wires shall be attached to power wires by soldering or by fastening under a set screw in a lug attached to the trolley hanger, or by such other devices as will prevent the wires from becoming loose.

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[57] This paragraph is an amended form of the original and is approved by the writer and other engineers of the bureau.

All wiring shall be supported on incombustible, nonabsorptive insulators which shall separate the wires by at least an inch from the surfaces wired over. Wires of opposite polarity shall be kept at least 5 inches apart. No wires smaller than No. 14 A. W. G. shall be used for lighting circuits.

(*b*) When the rail is used as a return for lighting circuits, the return wire shall be attached to the rail in an approved manner. This ground connection shall be made of not less than No. 8 A. W. G. copper wire, which shall be buried below the surface and carried to the side of the entry and thence on approved insulators to the roof or to a point at least 7 feet above the tract.

(*c*) All [electric light] sockets shall be of the weatherproof type and have no exposed metallic parts.

Signal and telephone circuits.—(*a*) Underground battery signal circuits and telephone wires shall not be installed on the same side of any entry as trolley wires or other power conductors. Where signal or telephone wires cross trolley or power wires, they shall be insulated and boxed in or incased in a conduit.

(*b*) Suitable precautions shall be taken to prevent electric signal or telephone wires from becoming grounded or from coming in contact with other underground electric conductors, whether insulated or not.

Shot-firing circuits (inside firing).—(*a*) Special precautions shall be taken to prevent shot-firing conductors from becoming grounded or from getting in contact with other electric circuits.

(*b*) Wires used in firing single shots within the mine shall be rubber covered and not exceed the following lengths: Six hundred feet for No. 14, 350 feet for No. 16, or 200 feet for No. 18.

Shot-firing circuits (outside firing).—(*a*) In coal mines employing the system of firing shots electrically from above ground [58] an underground metallic circuit shall be employed. All shot-firing lines shall be adequately insulated. The two wires that form the circuit shall be placed on the side of the entry or passageway opposite from that on which the trolley wire or other power wires are placed.

(*b*) The following switches shall be installed in the shot-firing circuit: No. 1, a locked firing switch in the shot-firer's cabin; No. 2, a locked switch in the power house; No. 3, a 5-foot lightning gap (disconnecting switch) at the foot of the shaft or slope or at the drift entrance, which switch shall be arranged for grounding the incoming circuit when not in service; No. 4, a locked switch at the entrance to each heading or side entry; No. 5, a switch at the mouth of each working place.

(*c*) Following special precautions shall be used in operating outside shot-firing systems: Detonators shall not be connected in straight parallel; that is, no single detonator shall be connected across the firing circuit. No. 5 switch shall be closed first, then No. 4, etc., No. 1 switch nearest the generator being closed last. This switch (which is the shot-firing switch) shall be closed but once and shall not be left closed for more than 0.2 second. The timing of the switch shall be accomplished mechanically (and arranged so that closing can not be accidentally repeated). No switch shall be closed until all men have left the part of the mine controlled by the switch. All men shall be checked in and out of the mine.

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[58] See pp. 66–67.

LIABILITY OF ELECTRICAL MACHINERY AND CIRCUITS TO IGNITE GAS

Stationary electrical machinery that is properly situated is not nearly so liable to cause ignition of gas or of dust as portable or movable machinery, because stationary machinery can be protected more easily and there is some choice of location. Stationary electrical machinery includes that at transformer stations, main pumping stations, air-compressor stations, main underground hoists, and underground booster fans permanently situated in pure intake air.

Ordinarily, stationary electrical machinery and power circuits in gassy mines can and should be in pure intake air, and their surroundings should be fireproof. The stations for electrical machinery can be situated where there is no difficulty in reaching power lines that are installed in the most approved manner.

On the other hand, in gassy mines there is potential hazard when nonflame-proof electric motors are used to drive unattended machinery, such as pumps and blower fans,[59] at or near the faces. Even though placed in what normally is intake air, such fans have caused disastrous explosions when ventilation was interrupted.

The most dangerous conditions arise when ventilation has been interrupted, as by the main fan being stopped for repairs, and after a too hasty inspection for gas electrical switches are thrown in to start a fan or pump equipped with an automatic starter.

In gassy or slightly gassy mines it is highly dangerous to start electrical machinery, even that which is in the intake air under normal conditions, until thorough inspection has shown no gas in the vicinity and no body of gas that may be carried to the electric motor by the restarting of ventilation. The use of permissible electrical machinery greatly minimizes the danger of ignition. Such machinery, however, is not intended for continuous operation in explosive mixtures of gas; moreover, as previously stated, there are possibilities that gas will be ignited by shorting of the power circuits from falls of roof that may happen while the ventilation is interrupted. A certain amount of danger also attends the use of small semipermanent hoists, such as may be used in panel workings in pitching coal beds.

Methods of installation, including the sectionalization of the main electrical circuits at intervals not exceeding 2,500 feet, are described under "Suggested safety rules for installing and using electrical equipment in coal mines."

Automatic starters and uninclosed or nonpermissible switches should not be employed in gassy mines.

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[59] See description of use of blower or auxiliary fans on p. 37.

In mines subject to large or unexpected inflows of inflammable gas from the faces or after falls of roof the use of compressed-air machinery in the working places may deserve consideration. The compressors, which may be electrically driven, can and always should be placed in fresh air. The alternative is to use permissible storage-battery trucks for driving machinery of approved types.

If small pumps not driven by compressed air are required in face workings or in return air, they should be permissible electric pumps that are supplied by cables put in trenches or in buried pipes so that falls of roof will not cause shorts, or that are operated by permissible storage batteries.

Imperfect bonding of the mine track when that is used for the return conductor of a trolley system or of electric machines is a source of danger in working places, because stray currents cause premature shot firing or in gassy mines ignite gas. Electric sparking has been seen inby the end of a trolly line, also inby where machine cables were connected; such sparking is caused by imperfect bonding or by breaks in the return conductor.

Haulage accidents are considered on other pages in the section so headed.

EXPLOSIONS CAUSED BY ELECTRIC CIRCUITS IN HAULAGE WAYS

Trolley locomotives, which have become the chief means of haulage in the bituminous coal mines of this country, have caused many explosions, most of which were due to ignition of fire damp in or near the face workings or in entries on the return air.

Some explosion disasters have been caused by the direct ignition of coal dust by electric arcing which followed the wrecking of a trip of cars that knocked out timbers and stirred up a dense cloud of coal dust. Five explosions that unquestionably started in this manner were on intake haulage ways, and four of them started not far from the mouth of the mine.

Explosion 1 occurred in a Colorado mine. While running down grade at high speed on a dusty double-track roadway, a trip of loaded cars drawn by a locomotive broke in two about 800 feet from the mouth of the intake drift. The front cars of the rear half jumped the track and knocked out timbers; in consequence the trolley wire came in contact with the steel bodies of the cars and undoubtedly caused electric shorts. Trips running down grade at high speed in this entry ordinarily stirred up a great deal of coal dust. Evidently more dust was stirred up locally by the bumping of cars loaded above their sides, and ignition undoubtedly resulted from the arcing.

Explosion 2 was in a New Mexico mine and was similar except that it occurred farther from the mouth of the intake entry.

Explosion 3 happened in an Alabama mine. A runway trip on an intake incline slope jumped the track, cut a power cable, brought down wires, smashed up at the foot of the slope, and doubtless stirred up a heavy cloud of coal dust. It was believed that the arcing of the power cable caused the ignition, but in any event the ignition was electrical and in pure intake air.

Explosion 4 occurred in a Colorado mine. A trip on an intake slope broke apart; the rear half, running back, probably caused an electric short when it wrecked and knocked down timber and power lines.

Explosion 5 occurred in a Pennsylvania mine under similar circumstances, except that it took place farther in the mine.

LIMITING USE OF TROLLEY LOCOMOTIVES TO AVOID IGNITION OF GAS AND COAL DUST

Although trolley locomotives are a source of possible ignition of gas or dust the bureau believes that they are reasonably safe for use (1) if in gassy mines locomotives and the trolley wire are kept strictly in intake air which does not pass through active or unsealed working places and has received no return from these places, and (2) if all trolley roads in gassy or nongassy mines are thoroughly rock-dusted. In gassy mines, however, under no circumstances should the trolley wire extend beyond or inby the moving air current; that is, it should be kept outby any open crosscut carrying the ventilating current from the intake heading to the return heading of any pair of entries. These restrictions on the use of trolley locomotives in gassy mines should also apply to open or unapproved storage-battery locomotives.

COMBINATION TROLLEY LOCOMOTIVES, INCLUDING TROLLEY

The above restrictions regarding trolley locomotives apply to different combinations of the trolley locomotive, such as (1) trolley locomotive with crab and electric hoist, (2) trolley locomotive with reel and cable, (3) trolley locomotive and storage battery.

The restrictions also apply to open or nonpermissible storage-battery locomotives.

Any of the foregoing equipment will make sparks, although these are not so observable in open storage-battery locomotives as in trolley locomotives, and if inflammable gas is present in dangerous amount is liable to ignite it.

A new type of reel locomotive is being introduced in which the motors and controllers are made flame proof and the trolley-pole connections are cut out by an interlocking device when the reel is used for going into headings and rooms. The intention is to use this type of locomotive in slightly gassy mines, but the arrangement of the current-taking devices has not yet been approved by the Bureau of Mines. The chief hazard in the arrangement is through the cable being run over or pulled apart.

PERMISSIBLE STORAGE-BATTERY LOCOMOTIVES

Unquestionably the safest method of electric haulage is by permissible storage-battery locomotives. These locomotives can be used in working places and in the return air where the percentage of gas is kept within suitable limits. The best mining practice, even in mines acknowledged to be gassy, requires that the return air of any split shall contain less than 0.5 per cent of methane, and that there shall be no standing gas in either idle or working places.

EXPLOSIONS AND FIRES FROM LEAKAGE OF NATURAL-GAS AND OIL WELLS THROUGH COAL MINES

In some coal fields, notably in western Pennsylvania and northern West Virginia, where natural gas is found in strata below the coal beds and the wells pass through or near coal mines, the development of both gas sands and coal beds has increased the danger of mine explosions.

In many mining districts the rights to bore for gas and oil existed before the coal beds were opened under lease or fee. The earlier gas wells were drilled without any thought of future development of coal, and when certain wells no longer produced oil or gas in paying quantities, as much of the casing as possible was pulled; then the wells usually caved at the top and ultimately left no trace. Hundreds of such abandoned unknown wells, of which there is little or no record, exist in some fields. Gas confined by the caving at the top of the well is under considerable pressure, and in some instances it has leaked into mines, to be ignited by open lights or electric sparks from open motors and cause explositions and fires.

This menace led the mining companies to leave pillars of coal around abandoned or active wells whose location was known. Pillars, however, do not prevent escape of gas into mines, for coal beds are permeable, but they do protect casings from the effect of mine caves.

SIZE OF PILLARS AROUND WELLS

The size of pillars has ranged from 40 to 100 feet square. Public conferences have been held with mine, gas-well, and oil-well operators to draft regulations. The first of these conferences was held under the auspices of the Bureau of Mines at Pittsburgh, Pa., February 7 and 8, 1913. A record of the conference is given in Bulletin 65.[60] The code of rules adopted by the committee appointed at the confer-

[60] Rice, G. S., Hood, O. P., and others, Oil and Gas Wells Through Workable Coal Beds: Bull. 65, Bureau of Mines, 1913, 101 pp.

ence was subsequently published in Technical Paper 53.[61] A record of certain explosions also appears in the transactions of the West Virginia Mining Institute.

Already different States had enacted laws and some courts had rendered decisions regarding the measures that should be taken, under specific conditions, to protect the lives of miners. The report of the conference at Pittsburgh was preliminary; it had some effect on legislation in certain States but did not result in uniform regulations being adopted by all the States concerned. Moreover, the code proposed was not generally accepted by mine operators or by gas and oil companies. As the problem is becoming more acute as more mines are opened, mining becomes more intensive, and more wells are drilled, the American Institute of Mining and Metallurgical Engineers in 1925 appointed a committee to try to formulate an acceptable code. This committee had not completed its work in March, 1927.

An example of the difficulty faced by mine operators in western Pennsylvania and northern West Virginia is afforded by one large mine which has 120 wells passing through the coal within the boundaries of its property. Not only must a large amount of coal be left unmined in the pillars, but great care must be exercised that there is no leakage from the wells.

In the report of the Pittsburgh conference (Bulletin 65, Bureau of Mines) appears a notice of leakage from a closed-in well near Monongah, W. Va. The gas, which was under high rock pressure and was confined by a cap over the outer casing, leaked past a packer in the well and also through a porous bed, fractures, or a line of weakness in the rock underlying the coal and entered two adjoining mines separated by a thick boundary pillar.

In one of the two mines a gas spring issued 2,300 feet from the well. Explosions, one of them causing a mine fire, occurred in each of the two mines on the same night, but fortunately only a few men were in either mine; the explosions were small, and but three men were killed. Other examples are known of explosions and mine fires caused by leakage from wells. So far there have been many narrow escapes, but luckily no large disasters.

Leaving a pillar around a well does not remove all danger of leakage; where pillars are withdrawn in the vicinity, ground movement or subsidence of the strata may break the casing above the mine and allow gas to seep into it. The bituminous report of the

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[61] Hood, O. P., and Heggem, A. G., Proposed Regulations for the Drilling of Gas and Oil Wells: Tech. Paper 53, Bureau of Mines, 1913, 28 pp.

Pennsylvania Department of Mines for 1895 describes an explosion of this kind at the Brier Hill mine October 17, 1895, in which three men were badly burned, one of whom died.[62]

PRECAUTIONS RECOMMENDED FOR GAS AND OIL WELLS DRIVEN THROUGH COAL MINES

Until a standardized code has been adopted, the following general practices are suggested:

1. An extra casing should be set through the coal bed being mined or through any workable coal bed that is likely to be mined within the lifetime of the well. It should be seated at least 20 feet below the coal bed and sealed with cement put in under pressure.

2. An additional precaution when a well is expected to be long lived is another casing inside the first, extending 10 feet below it, and also seated in cement. (The gas tube is put inside of the outer casing.) All of these casings (not including the gas tube or tubes) must be vented to the open air.

3. The gas-tubing packer should be put in below the casings to seal off the gas from the lower strata and keep it from entering between the tubing and the casing.

4. When a well is to be abandoned the outer casing in and above the coal beds should be left in place—that is, not pulled—and the hole filled from bottom to top with mud fluid. This filling will prevent any accumulation of gas under high pressure which might enter part of the mine if the outer casing failed later by corrosion or rupture.

5. The location of all wells should be carefully surveyed and records of the boring and subsequent history should be made a matter of permanent record. The mine operators should have copies of such records or have access to them.

6. When the position of a well is known, a pillar of coal should be left around it. The size of this pillar will be determined by the thickness of the coal bed, the depth below surface, and the inclination of the bed. A coal pillar less than 50 feet in diameter is not advisable. On the other hand, a pillar more than 100 feet in diameter seems unnecessary when care is taken in drawing near-by pillars and pack walls are first placed around the pillar.

7. If an oil or gas well penetrates open workings of a mine the casing should be surrounded with a cylinder or prism of concrete at least 6 feet in diameter and a pack wall carefully built around it. If a gas or oil well has penetrated abandoned or inaccessible workings of a mine these should be carefully sealed off from the active work-

[62] Rice, G. S., Hood, O. P., and others, Work cited, pp. 28–29.

ings by tight stoppings, and a hole should be bored from the surface near the well and at a high point in the workings to draw off any accumulation of gas coming from the well.

BARRICADES AND REFUGE CHAMBERS

Although everyone hopes that the employment of all known preventive methods will minimize the mine explosions and fires that entrap men, no mine operator is justified in assuming that no unusual occurrence, careless act, or mistake will ever cause a disastrous fire or explosion in his mine. On this account it is advisable for miners and officials to know and to rehearse frequently the procedure to be followed if men are entrapped by gases from explosions or fires.

For an explosion to penetrate all parts of a coal mine is exceptional. Records have shown that in what may be termed an average explosion only about one-third of the men who die are killed outright by the force of the explosion or by burns. Possibly another third are not burned or killed by violence but die immediately, almost without a chance to move, from inhaling afterdamp low in oxygen and high in carbon monoxide. The remaining third in this theoretical average disaster are in some panel or part of the mine at a distance from the area traversed by explosion. Because of the destruction of stoppings and overcasts farther out the afterdamp enters these distant workings by diffusion, and the local air currents move very slowly.

It has often happened that the men in these parts of a mine could have escaped later if they had remained in their working places. For example, in the Primero mine (Colo.) disaster of January 31, 1910, which killed 75 men, 11 men who were in a branch entry tried to get out too soon. All but one died of suffocation; the eleventh was found unconscious but was revived. At the Starkville (Colo.) disaster, which killed the entire night shift of 56 men, about 20 men in a corner of the mine that was not penetrated by the explosion gathered their dinner buckets and walked about 1,000 feet toward the entrance; then they were overcome.

BARRICADES

Deaths in mine-fire disasters virtually are never caused by flame, but by inhalation of suffocating or toxic gases. In the Cherry mine (Ill.) fire November 13, 1909, 259 men were suffocated and 13 attempted rescuers were burned on a cage. Both exits (shafts) were blocked by fires. Twenty men in one part of the mine, under the leadership of an alert assistant foreman, retreated to a point near the head of a pair of entries and erected barricades or dirt stoppings across each entry. Before barricading they removed a door farther out to short-circuit the gases from the fire in anticipation of the time when the ventilating current would be restored; otherwise the ventilating pressure might force gases through the intake seal. The fires in the shafts had been so severe that the shafts were sealed after attempted exploration. Later the seals were broken, men entered with breathing apparatus, and exploration began. Then ventilation was partly restored, and seven days after the fire the 20 men were rescued alive.[63]

Including the Cherry and later disasters, there have been in this country 17 mine explosions and fires in which miners erected barricades or started to do so. In five instances the barricades sealed off the poisonous gases imperfectly or assistance came too late; in other instances some of the men tried to escape too soon; 109 in all were lost from these causes. However, in all 344 were saved by remaining behind barricades for periods ranging from 2¾ hours to 7 days. Sixteen of the seventeen examples are described in Miners' Circular 25,[64] which also gives general recommendations.

In slightly gassy or gassy coal mines (classes 2 and 3) a place which gives off no methane, if one can be found, should be selected for barricading, as methane will gradually push out the air. Such a place may not be at the face but in old rooms farther outby. The danger of open lights behind a barricade was shown by an explosion in a barricaded place in the Kathleen mine, Illinois; seven men were killed probably by the explosion which occurred behind the barricade. If possible, a place should be selected where water can be had by digging a small sump.

REFUGE CHAMBERS

The construction or arrangement of refuge chambers has been much discussed. Some chambers in European mines have saved life. A few have been constructed in this country. The matter is discussed in Technical Paper 24.[65]

The proposal merely to fit ordinary rooms in different parts of the mine with emergency doors and stoppings ready for use and also with certain supplies of water, canned goods, etc., and self-rescuers (of an approved type) was made in a paper read before the West Virginia Coal Mining Institute June 7, 1910.[66] The type of self-rescuer then proposed did not prove successful. Meanwhile, how-

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[63] Rice, G. S., "The Cherry mine disaster": Trans. Coal Min. Inst. America, December, 1909.

[64] Paul, J. W., Pickard, B. O., and von Bernewitz, M. W., Erection of Mine Barricades During Mine Fires or After Explosions: Miners' Circ. 25, Bureau of Mines, 1923, 28 pp.

[65] Rice, G. S., Mine Fires, a Preliminary Study: Tech. Paper 24, Bureau of Mines, 1912, pp. 25–26.

[66] Rice, G. S., "Refuge chambers in coal mines," pp. 62–75.

ever, a self-rescuer of another type has been officially approved by the Bureau of Mines.

The cost of a refuge chamber may be small, and the knowledge of where they might find protection would be most valuable to men in time of disaster. Moreover, rescue parties would know where to look. In particular, such places would be of value if they were situated where prospect boreholes had penetrated the coal bed before mining. The holes could be cleaned and recased at little expense and could admit fresh air, drinking water, and food supplies as needed.

At the Harwick mine, near Pittsburgh, Pa., three very complete refuge chambers have recently been installed and two 8-inch holes bored from the surface into each chamber. There are motor-driven blowers at the top of one of each pair of boreholes, and a small power hoist for lowering supplies.

FALLS OF GROUND

As Table 1 shows, falling material (rock or coal) from roof faces or pillars causes by far the largest number of accidental injuries and deaths. In years when the production of coal was normal all kinds of falls in coal mines of the United States have taken about 1,200 lives annually or have caused about one-half of all fatalities. Manifestly all possible steps should be taken to reduce this fearful toll of deaths to a minimum. Moreover, these deaths do not represent the entire cost in human suffering; taking a ratio of injuries to fatalities similar to that in metal mines (50 to 1) would indicate 60,000 injuries from falls of rock or coal in a year.

Most accidents from falls happen in the face workings. In most coal mines in this country the miners do the timbering in the working places, and traditionally they are responsible for the care of the room, entry heading, or pillar working where they chance to be employed. State mining laws do not fully establish responsibility for propping, posting, or putting up enough timber sets. In general, however, the miner is supposed to put up timber enough for the proper support of his working place; the operator, through the mine foreman or underground manager, is supposed to keep enough timber handy to the working place and to see, through daily inspection by some official, that each miner bars down loose pieces of top or sides and sets props or otherwise timbers his working place. The courts have usually decided that final responsibility for his own safety rests upon the individual workman, but if another person is injured through the fault of a fellow workman the operator is usually held guilty of contributory negligence.

In some mining districts the miners put up only props and cap pieces, and when the roof requires timber sets of two or three pieces the company timberman does the work or the miner is paid so much per set. Any barring, spragging, or propping of the coal face necessary in high coal is considered to be the miner's duty.

In new special methods involving the use of loading conveyors or drag scrapers in longwall or in long-face mining, when a squad of miners is employed, propping and timbering are usually done by special company timber men.

TIMBERING TO MINIMIZE FALLS

The need and amount of timbering required to attain maximum safety depend upon these factors:

1. Character of immediate roof, such as draw slate or top coal, as to strength and thickness.

2. Character of main roof, as to strength.
3. Width of working place in advancing entries and rooms.
4. Behavior of roof in pillar work or in longwall or long-face work.
5. Maximum load on pillars from overburden; that is, total weight due to depth and ratio of mine area to excavated area, or unit loading of pillars with reference to their unit compressive strength.
6. Dip of coal bed.
7. Time any timber has to function before pillars are withdrawn.

DISCUSSION

Combinations of the several factors in the coal mines of the United States are so various that it is impossible to give more than general recommendations in this handbook. Coal is worked in benches 2 to 24 feet thick; moreover, the roofs range from the extremely strong standstones of some New River mines in West Virginia and the sandstones and shales in the anthracite region to the extremely weak "soapstone" (shale) of the longwall field of northern Illinois. It must be assumed that the props and timber selected are strong enough for the purpose and that the diameter of the small end of props is at least 4 inches (exclusive of the bark) for props up to 4 feet long, about 5 inches for those up to 8 feet in length, etc.

TIMBERING IN ROOMS FOR ROOFS OF AVERAGE STRENGTH

Under average conditions of roof in rooms 16 to 24 feet wide there should be two to four lines of props. The lines should not be over 7 feet apart, and the props in any line should be 3 to 6 feet apart. All props should have good cap pieces. Where the roof is weak or slabby three-piece sets (two posts and one crossbar) should be used over the trackway.

ENTRIES

A mine roof so strong and so slightly affected by weathering that little or no timber is required is very exceptional. Many roofs appear to be sound and strong when the entry is first driven but develop weakness after a time. In many mines this weakening is the result of bad layout; too large a proportion of coal is mined in the advance work, and the pillars left are too narrow and are broken by unnecessary openings or by openings that are too wide. In consequence, the pillars carry too much weight.

Many roofs in entries where strong pillars are left would be protected from weathering and would stand indefinitely without timbering if "gunited" immediately. A striking example of this can be seen at the Bureau of Mines experimental mine, near Pittsburgh, where entries, gunited ribs, and roof have stood, with some renewals of gunite in patches of the roof, without timbering for 15 years. At many drift mines in that district the roofs are "cut up" high and have required much timbering.

In general, timbering done promptly and with good lagging saves costly cleaning up of falls later and much expensive retimbering; most of all, it prevents accidents from falls. In entries used for haulage it is advisable to set the posts back in the ribs so that they will not be knocked out by derailments.

When high falls do occur the writer believes it is a mistake to use cribs over timber sets because (1) the weight is usually thrown on the middle of the collar (cap or cross timber), the part most easily broken, and (2) the cavity provides a place where gas can collect and coal dust can lodge.

Better methods, in the order of their desirability, are: (1) To use a concrete or brick arching and fill in above it with débris; (2) to use I beams with light lagging, preferably concrete slabs, and fill above; and (3) to put in timber sets above, preferably with the legs resting on notches in the ribs or, if necessary, superimposed on the timber set below. If the height justifies it a runway may be placed over the collars of the lower set to permit regular inspection by the fire boss or foreman.

TIMBERING IN PILLAR WORKINGS AND RETREATING LONGWALL

Miners should use plenty of temporary posts and place them under unsound pieces of roof. Miners or company men should put up systematic lines of posts or breaker props parallel with the gob line to protect themselves and others fully; such props should not be drawn before a new line is set up. Posts should be withdrawn by sylvesters (chain and lever) or similar devices to avoid the risk of falls catching miners. If the roof is very strong, open cogs or cribs should be used in systematic lines, so that one aids another. Recently in Germany extensible easily lowered steel props are being much used.

In certain new methods in use at one group of mines in the United States 100-ton hydraulic jackscrews placed in lines parallel with the face have proved a mechanical success in connection with conveyors.

For safety and success regular lines of props 3 feet or less apart should be used; if the gob is not well packed supplementary hollow cribs or cogs are necessary. Care must be taken not to break the roof. On the other hand, if the roof rock is pliable, like shale, it should bend and be gradually brought to rest by the pack walls, which compress solid under the weight. The bending of the roof over the edge of the longwall face makes the mining of coal easy. If a roof is so massive and strong that it will not bend, it must be allowed, or forced to break down, and sometimes blasting is required. The line of break can be established by placing cogs or cribs or by using one, two, or more lines of "breaker props," otherwise the roof if not controlled is liable to shear off at the face and catch the men.

In European coal mines the roof is generally shale at the depths mined (1,500 to 4,000 feet), and under such pressure that it is very weak and slabs off easily. Work under such roof would be extremely dangerous were the most careful timbering methods not used. In France and Belgium posts at the face (usually a longwall face) are put in two, three, or four lines, 3 feet apart either way. Stringers parallel with the face are placed over these, generally extending over three posts. Lagging poles are put in over the stringers, and resting on these, against the roof, are small poles and twigs to catch any small pieces of loose roof. In the Courrières mines in the north of France, which for a generation have earned a reputation for fine timbering and the lowest record of accidents from falls, the lagging poles extend into hitches picked into the face at the top before the coal is undercut. The face ends of lagging poles are supported by temporary posts while the coal undercut is being mined out and are subsequently caught up by the next line of posts and stringers.

To show how accident rates from falls of roof have been lowered by better support of roof, the figures in Table 5, from the annual report of H. M. chief inspector of mines of Great Britain for 1924, are presented.

TABLE 5.—*Average number of deaths per annum and average annual rate by decades from falls of ground (rock and coal)*

Period	Average number killed and injured per annum		Average rates per thousand employed
	Deaths	Injuries	Death rate
10 years, 1873 to 1882	453		1.12
10 years, 1883 to 1892	460		1.00
10 years, 1893 to 1902	448		.76
10 years, 1903 to 1912	573		.74
10 years, 1913 to 1922	607		.71
1 year, 1922	551	[1] 62,928	.59
1 year, 1923	585	[1] 69,824	.60
1 year, 1924	607	[2] 65,101	.62

[1] Disabled more than 7 days. [2] Disabled more than 3 days; seriously injured, 1,816.

British "falls of ground" statistics in 1923 and 1924 have separated "falls at the face" from those occurring elsewhere and have given the number of deaths and injuries resulting therefrom and the accident rates on the basis of the number of man shifts of face workers. In Table 6 the number of shifts has been calculated to a basis of 300-day workers in the respective years, and the rates for deaths and injuries have been calculated separately.

TABLE 6.—*Number of 300-shift workers killed and injured and rate per thousand in Great Britain*

Year	Number of 300-shift face workers	Number killed	Number injured	Rate per thousand 300-shift face workers	
				Death rate	Injury rate
1923	410,070	389	[1] 54,657	0.95	[1] 133.00
1924	402,310	389	[2] 50,928	.97	[2] 127.00

[1] Disabled more than 7 days. [2] Disabled more than 3 days; seriously injured, 1,387.

The death rate from falls of ground in the face workings—where three-fourths of such accidents occur—when calculated on the basis of the number of face workers exposed to the risk, will be seen to be 50 per cent higher than when all falls are considered and the accident rate is calculated on the basis of all workers.

The death rates in Table 5 show gradual reduction in the accident rate from falls of roof, as increasingly stringent regulations were made to govern timbering, and there was closer supervision of the workings by deputies and assistant face bosses or foremen.

In contrast to this are the figures in Table 7, on falls of roof and coal in coal mines of the United States.

TABLE 7.—*Fatalities per thousand 300-day workers underground in the United States*

Year	Fatalities from falls	Per cent of all fatalities underground and surface	Fatality rate,[1] all fatalities underground and shaft	Falls only
1917	1,230	45.63	4.78	2.41
1918	1,294	50.16	4.54	2.52
1919	1,107	47.66	4.95	2.57
1920	1,134	49.91	4.32	2.36
1921	1,025	51.38	4.75	2.60
1922	908	45.77	5.51	2.72
1923	1,167	47.40	4.95	2.51
1924	1,062	44.22	5.41	2.54
1925	1,080	48.34	5.24	2.69

[1] Computed on number of 300-day workers underground.

The fatality rates in the United States from falls of roof and coal (see Table 7) are in recent years four times those for corresponding years in Great Britain (see Table 5); these comparative figures indicate that it is possible to prevent a large proportion of the accidents from falls of roof and coal in American coal mines if timbering is done more systematically. The additional cost of timbering in European practice admittedly increases the cost of producing coal. On the other hand, this expense would be partly or wholly offset by the lower total compensation paid for deaths and injuries.

Each mine operator should make studies and keep statistics of the accident rate from falls for each class of workmen exposed to falls. For example, privately kept statistics of one large group of collieries, which generally is very well handled and has accident rates lower than the average, showed that machine men suffered a disproportionate number of accidents from falls. The figures indicated the need of better timbering and more careful roof inspection before and during undercutting.

Each operator should give special study to the area of unsupported roof in the working places and compare this area with the accidents from falls.

RECOMMENDATIONS FOR PREVENTION OF ACCIDENTS FROM FALLS

Every mining company should adopt rules providing for systematic timbering; these should be printed and issued to every underground employee. If many of the employees do not read English but do read other languages, translations into those languages should be included.

2. In the book of mine rules it is advisable to illustrate by diagrams the simpler kinds of timbering that the rules require.

3. At meetings, preferably weekly, of mine foremen to discuss safety matters, timbering rules, their violations, and the accidents from falls should be discussed and improvements in rules considered.

4. Records of accidents from falls should be carefully kept and diagrams giving accurate measurements should be made.

5. Records of timber sent underground to different parts of the mine should be kept not alone as a record of mine cost but also in order that the unit amounts of timbering per ton of coal produced may be found and their relation to accidents from falls of roof or rock may be determined.

6. Foremen, assistant foremen, or face bosses should by daily inspection and inquiry make sure that every employee who has timbering to do is kept fully supplied with timber at a convenient point.

7. Although miners in working places are primarily responsible for protecting themselves from falls of roof or coal, the company has certain moral responsibilities. Consequently, officials should not rely

upon the miners protecting themselves, but should make frequent inspection; and if the roof in a place looks in danger of falling, the official should remain on hand until the posts or timbers he has ordered are properly set up.

8. Concentration of working places is desirable, because it tends to reduce accidents from falls, permits more frequent inspection of working places, and effects economies in machine work, in haulage, and in ventilation. Concentration can be had by good engineering in laying out the mine and arranging the sequence of working different sections.

9. Enough foremen or face bosses should be employed to permit inspection of each working place at least four times a shift and as much oftener as possible. In general, this means there should be at least one assistant foreman or face boss for each 25 miners.

10. In rooms 18 to 21 feet wide, with average roof conditions, there should be two lines of posts, and the props in each line 6 feet apart. In rooms over 21 feet wide there should be three lines of posts.

11. All posts should have firm, sound cap pieces at least 8 inches wide and 18 inches long, strong enough to spread the load.

12. Where the roof is poor there should be collars or bars over the trackway, and temporary posts with long cap pieces should be used close to the face.

13. In entries with average roof conditions timber sets should be put in at 6-foot intervals, even if the roof appears strong when fresh. When the roof is poor, the sets should be closer and lagging should be used.

14. In haulage ways the legs or posts of the sets should be set back into the ribs so a derailment of a trip will not knock out the timbers.

15. When the haulage ways will be used many years, steel I beams and steel legs or side walls will prove a paying investment as compared with retimbering several times. Steel is stronger than wood and under excessive load it bends instead of breaking short, as some timber does.

16. Guniting the roof and ribs or entries pays when the roof weathers, especially if the gunite is applied before weathering starts.

17. In longwall and long faces and in pillar work plenty of props should be used and placed in straight lines. Cogs or cribs should be used when the weight of the overburden is liable to cause the roof to shear off along the face, smash the props, and catch the men.

18. When workings are abandoned the timber can be removed for reuse and the roof allowed to break. Sylvesters, or levers with chains, should be used so that the men pulling the timber may be safe.

19. The company inspector or fire boss must examine every place in his district before the men are permitted to enter. He should first test each place for gas, then test the roof with a rod heavy enough for him to detect, by sound or feeling, any vibration of the roof. He should bar down any very loose pieces or "fence off" the dangerous place until he has completed his round and returned with some one to help him. Larger pieces that seem dangerous should be marked with chalk for barring down or timbering.

20. A company inspector, fire boss, or district boss should station himself at a designated place where all men who work in his district pass when going in at the beginning of the shift, so that he can notify those going to places that require barring or timbering.

21. An inspector or boss should not rely on his memory but should make a record in a memorandum book and hand it to the foreman or face boss or bosses of that district to transfer to memorandum books that each will keep. A report should also be made and sent to the responsible official of any shortage of timber supplies in the district.

22. Each miner on entering his working place should "sound" the roof and feel with the hand, or with another bar if the roof is high, whether it vibrates when struck. He should put up posts or timbers in the places marked or bar down the roof.[66a]

23. Picks should not be used to pull down roof, for a falling piece is liable to catch the man using the pick. The foreman should see that every miner has a suitable bar.

24. After the roof is made secure miners or loaders must bar off loose pieces on the coal face; they should be especially careful if the face is over 6 feet high.

25. If the face is very high—say, over 8 feet—and seems at all liable to slip off, sprags or props should be set against it until the loose coal has been mined off. Friable coal which has been undercut should be spragged or blocked to keep it from rolling over on the men.

26. Timbermen must use plenty of temporary posts in putting up timber until the permanent timber is in place. When heavy collars or beams are being put up, temporary bracing must be used to keep them from rolling over before they are secured in place.

27. Lagging should be used freely where the roof or ribs are scaly or friable; to put it up takes little time, and it is especially valuable for preventing falls along entries. A man rarely gets caught through the breaking of timber, as he is warned by the cracking, but a great many accidents from falls of small slabs would have been prevented by lagging.

[66a] Rice, G. S., Accidents from Falls of Roof and Coal: Miners' Circ. 9, Bureau of Mines, 1912, 18 pp.

28. Large mines would lessen their accidents from falls and effect direct economy in timber by employing a timberman instructor, who would constantly go about the mine showing miners and less experienced timbermen the right way of timbering.

29. In conclusion, falls cause nearly half the deaths and injuries in mines, and virtually all these accidents would be prevented by adequate timbering. Although the miner may be held responsible for any injury received through failure to timber his place properly, the company through its foremen is morally responsible for the character of the timbering and for having the timber properly used.

The Bureau of Mines is now making special investigations of the causes of accidents from falls of roof and coal. A similar investigation, entitled "Support of Ground," has been carried on for some years in Great Britain by the Safety in Mines Research Board.

HAULAGE ACCIDENTS

Haulage accidents in coal mines usually stand second only to falls of roof as a cause of death, the number ranging from 341 to 506 annually between 1917 and 1924. Statistics are not available as to the number of injuries from haulage accidents, yet there is little question but that the proportion of injuries to deaths is larger than for any other principal cause of mine accidents.

As Table 4 indicates, the largest number of individual accidents are from two causes, "run over by car or locomotive" and "caught between car and rib." These two represent 60 to 70 per cent of all haulage accidents underground. The use of main haulage ways for travel of all the mine personnel furthers many accidents of these two types and can generally be avoided by having a separate manway.

Conditions in many old mines make avoidance of travel on main haulage roads impossible, and in entries off which rooms turn it can not be avoided. Under the latter circumstances it is important to have enough clearance between the moving cars and one rib and to give suitable warning of the approach of trips. Such warning might be by an automatic bell on the locomotive or on the head car of a trip hauled by rope. The bell could easily be contrived to be operated by a mechanical or electrical device (the latter actuated by a storage battery).

Many accidents are caused by men being caught while coupling or uncoupling cars. Here, again, the clearance and the character of the coupling are important factors. Care in the handling of trains of cars during coupling is important. Large, heavy cars should have automatic couplers.

Another class of haulage accidents is incident to the spragging or unspragging of car wheels in a contracted space between the cars and the rib. Here any piece of coal, rock, or loose timber piled at the side may cause a man to stumble and get caught. The remedy is to keep the passage cleaned up, to have more clearance, and to use side-operated brakes instead of sprags. Accidents of these classes are largely preventable by proper layout of the tracks and switches, use of the best design of mine cars, and good organization.

Runaway cars or trips cause the next largest number of mine-car accidents. A very large proportion of such accidents occurs in dipping beds. The remedies are to install automatic catches or derailing switches at the top of every slope and to use gong signals if a trip does get away.

PRECAUTIONS

On man trips on slopes automatic catches of some kind should be used. It would be desirable to have them operate for a descending trip when the speed exceeds 15 miles an hour. For ascending trips strong "dogs" or catching irons are much used; for descending trips several types have been designed but are little used.

Where men are lowered or hoisted in ordinary car trips it is highly important that a second rope shall be fastened the full length of the trip over the top of it and secured by a clip to the hoisting rope above the socket.

An alternative method is the use of safety chains for coupling the cars. Although this precaution provides for breakage of the regular coupling, it does not provide, as does the safety rope, for breakage of the socket or the attachments to the first car.

On main roads and slopes the signal wires should be within ready reach of the trip rider.

Hoisting-engine drum brakes, gravity-plane brakes, ropes, and fastenings should be inspected and tested by trial at least once a day before the principal shift is lowered down the slope.

In secondary slope roads or gravity inclines there should always be at the top of the slope or incline automatic stop blocks, released by the man at the top after signals are interchanged with the hoisting or gravity-incline engineer.

In dipping or raising rooms or headings, where the cars are lowered by rope and brake in balance, the car at the face of the room or heading should always be securely blocked in such a way that it can not be released accidentally before it is ready.

Electric or pull-bell signals are essential for the safe operation of any slope or incline on which the cars are handled by gravity or the grade is sufficient to start the cars running if they are not blocked.

Where men are hauled to and from their working places in trains of cars by electric-trolley locomotives, it is highly important that the trolley wires shall be far enough to one side and always on the same side, that they may be clear of the men in the cars.

Explosives should never be carried on man trips; serious disasters have been so caused.

Men should never be permitted to ride on top of loaded cars; this causes many accidents. No one should be permitted to ride on an electric locomotive except the motorman and the trip rider, if there is a seat for the latter.

Good lighting is an essential in preventing haulage accidents. Good lighting not only refers to the lights of the men who are authorized to travel haulage ways and of miners who are using the entry off which the working places turn, but also to locomotive lights and the head car of a rope trip.

Every trip of cars should have a rear light so that, if a trip breaks apart on a grade, the men on the roadway or on a following motor trip will see the runaway or detached cars.

Every mule or horse should have an electric light on its collar.

All haulage lights should be of permissible type.

INSTALLATIONS RECOMMENDED FOR SAFETY

In main haulage ways there should be a clearance of not less than 3 feet between the farthest projecting point on the side of the car and the rib. This clearance space should always be on the same side of the entry and kept free from débris. In addition, there should be refuge holes on slope roads, inclines, or wherever State regulations may call for them; such holes should not be more than 100 feet apart and as much less as the State law requires. Even though there is clearance for travel under ordinary conditions a runaway trip or car may jump the track; therefore refuge holes are needed. They should be whitewashed or otherwise clearly marked, should be kept free from all obstructions, and should be 6½ feet high, or not lower than the height of the haulage way if that is less than 6½ feet.

Trolley wires and power lines should always be placed on the side of the haulage way opposite from the traveling side. Where men must pass or cross underneath, trolley wires should be not less than 6½ feet above the rail measured to the sag of wire between supports, or else should be protected by boards or inverted troughs. The trolley wire should be sectionalized by switches in as short sections as practicable (see proposed standard electric practices on p. 76). It is recommended that the voltage of the trolley circuits be not greater than 275 volts, as then there is less danger of men being killed by shock if they touch the trolley wire.

Men should carry tools in the hand and not on the shoulder while in those parts of a mine where there are power lines.

Well-laid, well-ballasted tracks having heavy rails, fishplates, and close-laid ties are important features in preventing haulage accidents.

Mine cars are constantly being improved by safer running gear and good brakes, and should be arranged with safe couplings, preferably those that are automatic. The Bureau of Mines recommends tight-end cars, not only to lessen spillage of coal which is ground to dust on the rails, but also to reduce the number of derailment accidents caused by coal on the track.

Cars should be constructed to avoid sharp corners and projections that may catch men or animals. Projecting bolts should be avoided; flat-headed rivets are preferable. To lessen danger of injury to men it is better to place angle-iron side frames inside than outside the car body. This can be done without hindering the dumping of coal if tight-end cars and rotary dumps are used.

Standardized switches should be installed. The layout of haulage tracks—including passing tracks, sidings, and switches—is most important in preventing accidents.

Frog openings should have wood block fillers to prevent a man getting his foot caught.

Large mines use on their main roads a block system of electric signal lights that economizes time and increases safety.

Some mines provide for the haulage of loads and the haulage of empties in separate parallel entries, the safest plan where feasible.

The larger proportion of the accidents from haulage is avoidable. Much depends on the individual men, but a great deal depends on the management in laying out the haulage systems, putting in safety devices, and supervising haulage.

Detailed precautions in connection with haulage accidents are given in Mines' Circular 11.[67]

In large mines it is advisable to have an assistant foreman in charge of haulage, to see that cars and trips are moving regularly to and from the shaft or mine entrance, and that an equitable share of the empties is going to different parts of the mine. He should be capable of seeing how haulage can be improved with respect to safety and economy and constantly work toward that end.

The limiting of electric trolley haulage in gassy mines to pure air intake entries is discussed on page 81, and the necessity of rock-dusting thoroughly all haulage ways in bituminous mines is considered on page 52.

The great advantage for safety that electric haulage by permissible storage-battery locomotives gives, the avoiding of ignition of gas and dust, is stated on page 75. The prevention of fatalities by electric shock is referred to on page 101.

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[67] Jones, L. M., Accidents from Mine Cars and Locomotives: Miners' Circ. 11, 1912, 16 pp.

ELECTRIC SHOCKS

The extensive use of electrical machinery in mines has caused annually a considerable number of accidents from electric shocks. The fatalities have ranged (see Table 4) during the past eight years from 69 to 88 a year. Safety guards and better installations have kept pace with the increasing use of electricity, but have not gained rapidly enough to reduce the annual number of fatalities.

Half of these accidents are caused by direct contact of the man with the trolley wire and point to the need (cited earlier) of separate manways or of ample clearance along trolley roads, as well as the use of guards at places where the men have to cross under the trolley wire. Bars or tools carried by the men striking a live electric wire contribute an additional small number of deaths, one to four, a year. These could also be prevented by the means just suggested.

The substitution of storage-battery locomotives for trolley locomotives would practically eliminate deaths from contact with trolley wires.

Another specific cause of electric shocks is contact with machine power lines. Authoritative information is not at hand, but it is believed that the majority of these accidents are caused by attaching clips to the power line and to the grounded return, usually the track. If approved junction boxes are used, as in gassy mines, to lessen the danger of igniting gas, as recommended in connection with the use of electrical mining machines on page 75, this cause of accidents would be practically eliminated.

Each year there are a number of accidents from contact with mining machines. Evidently these happen because the machine frame has not been properly grounded or there has been some internal breakdown of the machine. Constant care is needed to keep machines in proper repair, and when they have broken down the power should be cut off at once. Approved or permissible machines are much less likely to cause such accidents because of the care with which they have to be constructed to pass the bureau's tests.

Other causes of electric shock are diversified, but in the majority of cases they are probably due to handling and making repairs on circuits and machines, such as pumps, without first cutting off the power.

One most important factor in the prevention of shocks is to have electrical machinery and circuits installed by trained and experienced men and under the supervision of a thoroughly competent official, who before appointment should pass an examination on all problems likely to arise in installing electricity in mines.

If a man receives a shock that disables him or makes him unconscious and he remains in contact with the wires, any near-by switch that will cut off the power should be closed at once; if no switches are close by and there is a steel bar or pipe at hand, it should be stood against the rail on the side on which the power is received and dropped upon the wires to cause a short circuit. Next, one should stand on a board or, if nothing better is at hand, a piece of dry cloth not in contact with metal,[68] grab the man quickly, and pull him off. (See Miners' Circular 5.)[69] Methods of resuscitation are described in the First-Aid Manual of the Bureau of Mines; briefly, if the man is unconscious, he should be treated by the Schaefer method.

[68] Clark, H. H., Roberts, W. D., Ilsley, L. C., and Randolph, H. F., Electrical Accidents in Mines, Their Causes and Prevention: Miners' Circ. 5, Bureau of Mines, 1911, 10 pp.

[69] Bureau of Mines, Manual of First-Aid Instruction for Miners (revised by R. R. Sayers): 1922, pp. 28–29, 33–35.

MINE FIRES

Mine fires, second only to explosions, are the happenings most dreaded in coal mining. During the last eight years the number of lives lost by burning or suffocation is not large, ranging from only 2 to 26 a year, but these small numbers are not a true measure of the hazard of mine fires, as shown by the Cherry mine fire, Illinois, November 13, 1909, which killed 259 men, and the fire at Price-Pancoast anthracite colliery, Pennsylvania, March 22, 1911, which killed 72 men.

Coal-mine fires probably can never be absolutely eliminated. Combustible material is being mined, and combustible equipment, including roof supports, track ties, doors, temporary ventilating stoppings, brattice cloth, electric insulation, and explosives, must be used to some extent. The material brought into the mine, rather than the coal itself, is the most prolific source of mine fires, hence the greater the use of incombustible material (stone, cement, steel, and iron) for all construction the lower will be the fire risk.

There will always be sources of ignition in a mine, and the danger of spontaneous combustion is always present, but these hazards can be minimized by known means.

Methods of illumination by incandescent lamps at shaft bottoms and improvement in portable miners' lamps have decreased the liability to those fires that start at entrances or junction points and cause the trapping of men. Another important measure in the prevention of fire has been the use of permissible explosives. The bureau recommends the use of these explosives for all coal mines (see p. 61); black blasting powder and dynamite shots will ignite gas readily, and many fires at the face were and still are caused by nonpermissible explosives.

A mine fire, especially in any gassy mine, is liable to cause a disastrous explosion. A number of such explosions have happened. In the mine at Delagua, Colo., November 8, 1910, an explosion attributed to a fire killed 72 men. A recent instance is that of the Horning mine, Pennsylvania, in which 20 men were killed by an explosion resulting from a fire. At the inquest witnesses testified that had it not been for rock-dusting the 400 men in the mine might have been killed. A synopsis of the principal coal-mine fires is now in press and will be issued as Bulletin 229, Bureau of Mines, Fifty-Nine Coal Mine Fires. The lessons derived from these disasters are of great value to mining men.

Fires in nongassy mines (class 1 coal mines, see p. 29) rarely cause explosions, but these have occurred. A fire caused an explosion in a mine in the Sheridan subbituminous district of Wyoming some years ago, and in 1910 a similar occurrence in a Colorado bituminous mine rated as nongassy killed 79 men.

There is no inherent reason why fires may not occur under conditions approximating those prevailing in a gas producer. If there is a fire in a passageway and it is fanned by a current of air, there will be a long stretch of glowing coals. Mine air in the inner workings is usually saturated or nearly saturated with water, and the heat of the fire distills more water from the coal and timbering. Oxygen in the air current would be consumed rapidly in passing through the fire zone, and the breaking up of the water in the air in the presence of hot carbon would cause production of large amounts of carbon monoxide. The heat of the fire would also distill hydrocarbons from the coal. Thus, a large amount of inflammable gas is produced. Whether or not the gas would be explosive when mixed with fresh air would depend upon the amount of carbon dioxide displacing oxygen in the mixture.

Obviously, however, under certain conditions an explosive mixture might be formed and an explosion result if there was a source of ignition, such as an open light or the fire itself. Ignition by the latter might result if the direction of the current of air and gas reversed for one reason or another; for example, if a fall of roof backed up the explosive mixture so it made contact with the live coals.

Although there have not been many such explosions in nongassy mines, their occurrence should be forestalled if possible.

CLASSIFICATION OF MINE FIRES

All mine fires threaten danger to personnel, but in varying degree, according to location.

1. Fires starting in and about shafts threaten the entire working force below ground. The most notable example of such a fire was that at the Cherry mine, Illinois. (See p. 73.)

2. Fires starting at or near the point where ventilating splits turn off, at doors, overcasts, and combustible stoppings between the intake and return of a ventilating split immediately threaten the safety of all the men on the split.

3. Fires starting in working places are rarely of immediate danger to personnel, but in a place producing much gas become a serious menace if not extinguished promptly, because of the possibility of explosions.

4. Gob fires if found smoldering before they become active are rarely a hazard to personnel, but if they have become active—that is, flaming—in a gassy mine are a menace.

Mine fires start in three general ways—by flame, by some form of external heat higher than the ignition point of the combustible present, and by spontaneous combustion or self-heating through oxidation, at first slowly, then more rapidly.

Flames or external sources of ignition that directly ignite combustibles are:

1. Open-flame lamps, igniting gas, wood, brattice cloth, oil, or other combustible.

2. Matches igniting gas, wood, or easily ignited combustible.

3. Burning tobacco, as unconsumed pipe tobacco or a cigarette thrown on rotted wood, cloth, or cotton waste.

4. Explosives in blasting, especially long-flame explosives with flames of long duration, such as black powder and dynamite, igniting coal, timber, or gas.

5. Electric arcs igniting coal, wood, gas, or combustible insulating material.

6. Electric hot wires, as of overloaded conductors, in contact with combustible insulating material, wood, or coal.

7. Electric incandescent lamps in contact with wood or cloth.

8. Flames of coal-dust or gas explosions or burning coal dust from explosions.

9. Steam pipes in contact with wood or coal. Steam piping was formerly much used for pumps and underground hoists, but now is rarely seen.

10. Fire in a ventilating furnace communicated to adjacent coal ribs. As ventilating furnaces are now permitted only in new small mines, this cause of mine fires is disappearing.

11. Indirect igniting sources of mine fires include gas blowers at the face, set on fire by one cause or another, igniting coal, and oil fires, as of lubricating oil, transported or stored underground, and gasoline as used for mine pumps, hoists, and locomotives.

As the use of gasoline as an internal-combustion fuel has been generally prohibited in coal mines by State mining regulations it is now rare. The bureau considers the use of gasoline in mines extremely hazardous, not only because of the danger of explosions and fires, but also, in normal mining, of the exhaust of the machines producing large amounts of carbon monoxide.

DISCUSSION OF DIFFERENT TYPES

Fires occur most frequently in working places, where timber or combustibles are ignited by any of the above agencies, or where long-flame explosives, especially black powder, ignite inflammable gas or the coal itself. In districts where such nonpermissible explosives are used fires are frequent, and some mines customarily have fire runners who go about the mine after the shot firing has been done to extinguish incipient fires.

Coal-mine fires caused by spontaneous combustion in the gob are apt to happen only in coal mines where there are peculiar natural conditions, such as the occurrence of finely divided pyrite or marcasite, which oxidizes rapidly, or where there are impurities which self-heat. It has been noted that most coals which absorb oxygen from the air rapidly are peculiarly liable to fire spontaneously in mines. In this country certain districts, such as central Illinois and Iowa, having high-moisture, high-sulphur, high-volatile coals are particularly subject to such fires. These coals also have thick "mother of coal" or charcoal partings (termed "fusain" by the British).

The subbituminous coals, which are high in moisture and in volatile matter, are very liable to spontaneous fires. Here pyrite is not involved, but rapid weathering and the disintegration of particles and consequent absorption of oxygen seem to be the reason for self-heating. The reactions which produce spontaneous gob fires on some occasions and in certain localities in the same mine and not others are not fully understood. It is also a curious fact that mines producing low-volatile coals and anthracite mines as well do not have gob fires, yet smokeless bituminous coals and coking coals of high rank fire spontaneously when stored in high (more than 20 feet) piles and sometimes in ship cargoes.

Such fires occur when there is much fine coal or dust in the mass; the fine coal shuts off the circulation of air that ordinarily carries away the heat of slow oxidation and thus permits the temperature to rise at an increasingly accelerated rate.

Surface piles of subbituminous or lignitic coals are almost certain to fire spontaneously. Such firing manifestly results from weathering, in which the inherent moisture dries out, causing shrinkage cracks and rapid disintegration; the latter, by exposing more surfaces, causes rapid absorption of oxygen with resultant heating from the chemical combination.

Some fires started by explosions of gas or dust are initiated around the margin of the explosion area, where the air reenters as soon as the explosion gases have cooled and contracted and furnishes a new supply of oxygen, causing the hot partly consumed dust, charred timber, or other combustible to rekindle and burn.

Underground storage-battery charging stations have experienced some bad fires. Hydrogen is given off during the charging, and imperfect electrical contacts are likely to cause sparking. It is evident that such stations must be thoroughly ventilated by an air current and be fireproofed. They should have iron or reinforced concrete doors closing from the outside, including slides or gates for closing off the intake and return air ducts, so that if a fire becomes uncontrollable in the station it can be completely sealed. It may also prove advisable to have liquid carbon dioxide tanks on the outside to inject gas through a pipe into the sealed station.

PREVENTION OF MINE FIRES

To prevent fires in shafts and splits, the most important precautions are:

1. The exclusive use of miners' portable permissible lamps (electric or flame safety lamps), whether or not the mine is gassy.

2. The proper installation of electrical machinery, apparatus, wiring, and fixed lights to minimize occurrence of short circuits.

3. Fireproof construction in shafts, shaft and slope "bottoms," overcasts, booster-fan installations, stables, pump rooms, transformer rooms, storage-battery charging stations, engine rooms, storerooms. repair shops, etc.

4. Emergency iron or concrete fire doors at critical points, thus sectionalizing the mine, and in connections to adjacent mines. These doors should be so installed that they may be readily closed and latched but unlatched and opened from either side. Hinged or sliding emergency fire doors should also be fitted at the top of shafts or at slope or drift entrances where there are wooden buildings or combustible materials adjacent. They should be so arranged that they can be closed from the open air by pull ropes or similar means.

5. Fireproof construction of the surface buildings adjacent to mines, particularly the ventilating-fan housing and building.

Fires in the working places can best be handled by making all equipment that is a possible source of ignition as safe as possible; suggested equipment includes permissible portable miners' lamps, approved electrical installations, permissible cutting machinery, and permissible explosives.

Spontaneous gob fires, those of the fourth class, can be minimized in effect by laying out the workings to provide strong ventilation, which will keep the gobs well ventilated and thereby prevent their temperature from rising above the critical point (which differs for different coals). When the mining has been finished in that working place or panel, if the coal or roof material is of a nature to fire spontaneously, the panel should be sealed off securely by tight stoppings; this suggestion is made on the assumption that pillars are not to be drawn or that the line of faces is not retreating regularly and rapidly.

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The ultimate best method of coal mining, it is generally acknowledged, is to take out a minimum amount (10 to 15 per cent) of coal on the advance, and then to concentrate workings and draw back rapidly all the remaining coal. If this is done, there is virtually no danger from spontaneous fires.

In advancing longwall, a system almost universal in Europe, spontaneous gob fires are infrequent, except in Yorkshire and South Staffordshire. In the thick Barnsley seam of Yorkshire, leaving the top coal in the gobs, because it is of poor quality, causes frequent fires. At one gassy mine, when a gob fire occurs, the face and the gob behind it are faced with a layer of sand and the face is kept open for the circuit of air. The fire center is then completely surrounded with sand or rock-dust packs, and the methane which chiefly enters along the faces is thus prevented from accumulating. This result would not be accomplished if the usual practice of sealing off up to the face on either side were followed.

Hydraulic sand filling, as used in dipping beds in Germany and France and to some extent in the Pennsylvania anthracite field where the practice originated, is the best preventive of fires in the working places; however, it is not generally applicable in the mines of this country, partly on account of the scarcity of gravel and sand in the coal-mining districts and partly because of the high cost and difficulty of using filling, if available, in beds that lie flat.

Mine fires caused by explosions of gas and coal dust obviously are best prevented by preventing explosions. It is important that mine rescue crews wearing approved breathing apparatus or masks find and extinguish these incipient fires ahead of and before the air current is successively advanced by reerection of stoppings.

ILLINOIS LAWS GOVERNING FIRE PREVENTION AT MINES

Following the disastrous Cherry mine fire (1909) the State of Illinois appointed a commission which drafted the most complete code for fire protection found in any State coal-mining regulations.[70]

FIRE-FIGHTING EQUIPMENT AND ORGANIZATION

Every mine should have adequate fire-fighting equipment, not only to prevent fires that may cause loss of life but to prevent destruction of property. Even if a shaft has a fireproof lining a fire may start near by and the flame go up the shaft as up a chimney. If the shafts or exits are wood lined, the escape of men may be cut off, as at the Cherry mine. Fire-fighting equipment may be classed as follows:

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[70] Rice, G. S., Mine Fires, a Preliminary Study: Tech. Paper 24, Bureau of Mines, 1912, pp. 42–47.

1. Stationary equipment, reservoirs or tanks, water lines, and hydrants on the surface and underground with necessary hose.

2. Portable or semiportable self-contained fire extinguishers. (*a*) Small extinguishers carried in the hand or on the back; (*b*) large fire extinguishers on trucks; (*c*) sand, rock dust, carbon dioxide snow, barrels, etc.

3. Bratticing material for building fire stoppings.

4. Telephone and alarm apparatus.

5. Emergency fire doors.

6. Breathing apparatus, carbon monoxide masks, and portable electric lamps.

7. Ventilating fans. (*a*) Provision for reversing main ventilating current; (*b*) portable blower.

8. Fire-fighting organization and maps.

DISCUSSION OF FIRE-FIGHTING EQUIPMENT

1. WATER

An ample supply of water at the mine for fighting fires on the surface or underground is a necessity. Where the natural supply of water is small, provision should be made for always keeping a large quantity (10,000 gallons or more) adequate for emergencies. Preferably the emergency supply should be held in an elevated tank on the surface so that water will be immediately available if anything goes wrong with the pumps.

Hydrants of the antifreezing type should be placed at strategic points in and around surface buildings and near the shaft and all places where there are fire hazards.

Water pipes should enter the mine in the upcast shaft, in order that there may be no danger of freezing; otherwise special provision should be made for circulating warm water. It is very desirable, however, to have down the intake shaft a supplementary pipe line, kept drained in cold weather but cross connected with the underground water line, to be used if fire affects the downcast shaft.

Underground hydrants or hose taps should be installed at intervals of not more than 100 feet in and around the shaft bottom. This should be a minimum requirement. It is highly desirable that waterline systems extend up to the working faces, as required by law in Utah. Such pipe lines are not only of value for fire fighting but in bituminous mines are important for keeping down coal dust at the face and for sprinkling mine cars at certain points in the entries.

2. FIRE-FIGHTING APPLIANCES

(*a*) **Hose and nozzle.**—Standard 2½-inch-diameter fire hose with a 1-inch smoothbore nozzle may be used on the surface. It is best to keep such hose on reels mounted on a two-wheeled truck and to store it in a fireproof building far enough from other buildings not to be endangered by fire.

Studies by the Illinois mining commission in 1910, confirmed by tests at the experimental mine of the Bureau of Mines in 1912[71] and further corroborated by a more recent investigation in the Underwriters' Laboratories in Chicago in 1924,[72] indicated that the best hose for fighting fires underground is a one-man hose, size 1½ inches. Such hose would be regarded as emergency hose, and if a fire was persistent a 2½-inch hose from the surface might be sent into the mine. A ¾-inch-diameter nozzle should be used for the 1½-inch hose.

All hose and connections in or around a mine must be standardized and hydrants must be arranged to allow reducers to take care of either size of hose, 1½ or 2½ inch, to be fastened on; and reducer connections with standard pipe threads should always be attached to fire hose, ready for emergency use if a pipe line is cut into.

There should always be at least one hose underground near the shaft, connected to the water-pipe line and placed on a fire-hose bracket. Experience has shown that hose stored underground tends to rot, hence at a few mines hose other than that near the shaft is placed in a trough along the side of the entry, where it can be so laid that by inclining the trough any water left in the hose can drain out.

(*b*) **Portable or semiportable self-contained fire extinguishers.**—Where a mine is not completely equipped with water pipes and hose it is very important that portable or semiportable self-contained fire extinguishers should be kept at certain stations on the surface and underground. When a fire starts immediate action is vital, and during the first few minutes of a fire almost any extinguisher will put it out, unless strong gas blowers are burning. These fire extinguishers should be of the standard type approved by the Underwriters' Laboratories (Chicago, Ill.) and should be examined and refilled from time to time.

Some companies have large fire extinguishers mounted on trucks; they are most useful on the surface. Underground their use is more limited, because of the difficulty of getting a clear track to the seat of the fire; that is, one unobstructed by empties or loads.

The standard fire extinguishers use either compressed air or carbonic acid gas under pressure, or the latter gas is generated chemically by the action of acid on soda to force out the water through the hose and nozzle. The carbonic gas in solution helps the water to extinguish a blaze.

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[71] See footnote 70.

[72] Tracy, L. D., and Hendricks, R. W., Small Hose Streams for Fighting Mine Fires: Tech. Paper 330, Bureau of Mines, 1925, 23 pp.

(*c*) **Special types of extinguishers.**—Carbon tetrachloride has proved of great value in fighting surface fires, especially electrical fires, as it is a nonconductor of electricity, but it must not be used in a close space or when there is no strong ventilating current, for when it is thrown on a fire phosgene and hydrochloric acid gases are formed. Furthermore, the undecomposed carbon tetrachloride vapor when concentrated acts like chloroform.

The use of carbon tetrachloride extinguishers, in an electrical fire on a New York subway train a few years ago, caused a number of persons to be overcome. Tests in the experimental mine fully convinced the Bureau of Mines engineers[73] of the danger of using these extinguishers unless a ventilating current carries the gases from the fire fighters or they wear breathing apparatus or suitable gas masks.

Foamite is a good extinguisher of an incipient fire, and as it produces only carbon dioxide when thrown on a blaze it is not dangerous for use underground; its foaming, spreading qualities tend to smother the blaze by putting a blanket of carbon dioxide in contact with the burning substance. It has been used to advantage in extinguishing oil fires.

Like water, foamite is an electrical conductor and should not be used as a stream on an electrical fire because of the danger of electrical shock to the fire fighters.

(*d*) **Sand.**—For extinguishing electrical fires boxes or covered cans of dry sand should be kept in all transformer and other electrically equipped stations. Moreover, there should be additional boxes or covered cans just outside such stations.

Sand is excellent for building fire stoppings between double walls. It has been used extensively for sealing pack walls in a large longwall mine in Yorkshire, England, that is subject to frequent gob fires.

(*e*) **Rock dust.**—The writer proposes the use of limestone dust as possibly better than sand in fighting electrical fires. It is finer, would have more covering qualities, and in contact with the fire would give off carbon dioxide. For general fighting of incipient fires rock dust has been used in certain Illinois mines with great success, it is claimed. Its use has been tested at the experimental mine near Bruceton, Pa., with successful results.[73a]

As rock dust is now being increasingly used in bituminous coal mines for preventing coal-dust explosions, it is advisable that rock dust be kept in cars in different parts of a mine at certain designated sidings, where it will be available for haulage to the seat of the fire;

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[73] Fieldner, A. C., and Paul, J. W., Gases Produced in the Use of Carbon Tetrachloride and Foamite Fire Extinguishers in Mines: Repts. of Investigations Serial 2262, Bureau of Mines, 1921.

[73a] Howarth, H. C., and Greenwald, H. P., Tests with Rock Dust for Extinguishing Fire: Repts. of Investigations Serial 2801, Bureau of Mines, April, 1927.

it can then be thrown upon the fire from buckets. It is probable that under certain conditions rock-dusting machines would be of great benefit in throwing dust forcibly upon the fire. Machines using flexible pipes and nozzles which could throw dust into rooms where electrical machinery was burning might be effective.

(*f*) **Carbon dioxide snow.**—Experiments made by the Mellon Institute investigators have indicated [74] that carbon dioxide snow may be of great benefit in fighting a fire. The liquefied carbon dioxide is taken into the mine in tanks, and special valve arrangements allow carbon dioxide to be discharged without the valve freezing, even though the dioxide turns to "snow" as it issues through the valve. If the fire can be approached so the snow can be thrown on it, the heat of the fire will melt the snow, thus cooling the burning material, and also form a blanket of carbon dioxide gas which tends to exclude oxygen from the fire. Under certain conditions, for example, where there is no ventilation, the fire fighters might have to use breathing apparatus.

(*g*) **Water barrels and buckets.**—In small mines where there are no water lines water barrels should be installed throughout. The Operating Regulations to Govern Coal-Mining Methods on the Public Domain give the following useful particulars about water barrels and are quoted herewith.[75]

> In every mine in which over 10 men are underground on any one shift there shall be a supply of water on the surface available for fighting fires in and about the mine. If this supply of water is not furnished through pipes, hydrants, and hose, it shall be kept in barrels of about 50 gallons capacity, painted red, with covers, and a 2-gallon bucket or can, painted red and marked, "Do not use except for fighting fire," shall be hung or placed immediately adjacent to each barrel. These barrels shall be maintained full of water. Barrels in a mine where pipe lines and hose have not been installed shall be placed near the bottom of each shaft or slope and at principal junction points not exceeding 1,000 feet apart on a main haulage road. Provision shall be made to keep the water in barrels or pipe lines from freezing. Chemical fire extinguishers having a capacity of not less than 2 gallons may be substituted for barrels of water.

3. BRATTICE MATERIAL FOR BUILDING FIRE STOPPINGS

It is desirable to have in mines certain storage places where material for fighting fires can be kept; these places may also serve as offices for the fire bosses and foremen. The stored material should include brattice cloth, boards, and scantling for the erection of temporary brattices. It is also desirable to store in unused crosscuts at strategic centers a certain amount of brick or concrete block, or the

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[74] See report of the Mellon Institute.

[75] Bureau of Mines, Operating Regulations to Govern Coal-Mining Methods and the Safety and Welfare of Miners on Leased Lands on the Public Domain: 1921, p. 34 (Sec. 100a).

equivalent, for emergency use. Building plaster in tightly sealed drums might also be stored.

4. TELEPHONE AND ALARM APPARATUS

The telephone is one of the handiest devices for use in and around mines, not only for giving fire alarms but for normal communication. Nowadays almost every mine of any size has a telephone system that connects in to the hoisting engineer and the office of the company. Underground gong alarms, as tried out in Illinois after the Cherry disaster, did not prove successful. Accidental alarms were sent which caused stampedes. On the surface, however, there is no reason why gong alarms can not be used effectively.

5. EMERGENCY FIRE DOORS

All stationary electrical machinery of permanent or semipermanent character—that is, serving for 5 years or more—should be housed in chambers or stations that are of fireproof construction or have fireproof linings and are provided with steel or concrete doors which can be closed from outside the chamber if a fire gets beyond control. It is also a wise precaution to have emergency fire doors to isolate sections of a mine on different splits of air current. Such doors, however, should be locked open to prevent accidental or careless closing, and the keys given to foremen responsible for the safety of the men.

6. BREATHING APPARATUS

Permissible oxygen breathing apparatus is highly important for coal mines that present fire hazards. For emergencies it is desirable to have six sets of oxygen breathing apparatus at the mine or at an adjoining station not over one-half hour from the mine. Approved carbon monoxide masks or approved all-service masks are most valuable to have in readiness for use at short notice, not only in a rescue station on the surface, but also in underground stations, such as the mine foreman's office and fire bosses' offices.

Miners' approved self-rescuers should be kept at these underground stations in considerable numbers. If a mine is not generally equipped with permissible electric miners' lamps, it is very advisable to keep at least 12 such lamps charged and ready for use. As an alternative, permissible flash lights should be kept in the emergency stations.

7. ARRANGEMENT OF VENTILATING FAN

Provision for reversing main fan.—Provision for reversing the main fan is now practically universal in all well-equipped coal mines and may be of vital importance in a serious fire. For example, it was thought that if the ventilating fan at the Cherry mine had been reversible and had been reversed immediately there would have been no loss of life. Under no circumstances should a main ventilating fan be stopped or the air reversed except by the direct instruction of the underground foreman or whoever is in charge underground at the time.

Portable blower.—A portable blower mounted on a mine truck was of great advantage a few years ago in fighting a dangerous fire in the Sunnyside mine, Utah. It enabled an advance to be made through smoke-laden entries; temporary brattices were used and the air forced ahead to allow direct fighting of the fire. A portable electrically driven fan in a gassy mine must be used with great caution; to avoid ignition of gas, the motor and wiring must be kept out of the return. Even in a nongassy mine inflammable gas, including carbon monoxide, is distilled or generated by the fire. It is possible that in future an approved motor fan driven by an approved storage-battery locomotive may have a wider use for fire fighting.

FIRE-FIGHTING ORGANIZATION AND MAPS

Organization.—Countless disastrous mine fires that might have been easily extinguished at the beginning became uncontrollable because the men at hand did not know what to do or how to proceed. The fire organization should be worked out before the fire occurs, and there should be weekly or monthly drills of those who are liable to be leaders. An easily understood program, with names given in the order to be notified in case of fire, should be framed behind glass and posted at critical points in at least a dozen places in and about the mine (including the foremen's and fire bosses' cabins and the supply rooms) at the foot of shafts or slopes and on the surface, and at the shaft landing, engine house, and office. A notice used in certain mines of Butte, Mont. is reproduced (fig. 1) as an excellent example of what such a notice should include.

Fire fighting.—One of the most important prefire measures is to have special maps for fire fighting prepared and kept up to date; copies should be distributed to the different foremen and in the underground offices as well as on the surface.[76]

The general fire-fighting map should be only a skeleton map of the mine, showing the shafts and entries, levels or headings, pipe lines and taps or hydrants, pumps, sumps, fire signals, and the ventilating system, including overcasts and doors, as in fighting some fires a change in the direction of the ventilating current might be essential.

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[76] Rice, G. S., Mine Fires, a Preliminary Study: Tech. Paper 24, Bureau of Mines, 1921, pp. 24–25.

One important aid for men who may have to escape from fire or from an explosion is an adequate system of signs marking the route to manways and to escape exits. These should be enameled in accordance with standard markers designed by the National Safety Council. Similar signs should also be put up at all important junction points and be kept clean. Luminous signs—that is, those with luminous paint or enamel—are of advantage in case the stationary lights are knocked out and some miners have lost their lamps.

GAS-ANALYSIS APPARATUS

Every coal mine subject to mine fires and every gassy (class 3) mine should have gas-analysis apparatus (see p. 20) for promptly analyzing samples of the return air from the fire in order that measures for withdrawing the men can be taken if the proportion of gas in the return nears the explosive point. At other times such apparatus is useful in determining the quality of the mine air in different working places and ventilating splits.

FIRE-FIGHTING PROCEDURE

1. The person who discovers the fire should use water, rock dust, or whatever is at hand to smother it if it is small, at the same time calling for help.

2. If the fire is too large when first seen to be extinguished by simple means, he should run to the nearest telephone, calling to the miners in the working places along the way to get out at once.

3. He should telephone the mine office and tell them who he is, where the fire is, and how large it is, then give what service he can in notifying men in danger from smoke and gases and assist in fire fighting.

4. The mine office will then telephone to (*a*) mine superintendent, (*b*) mine foreman, (*c*) leader of the fire-fighting crew underground, (*d*) rescue and fire-fighting station, (*e*) hoisting engineer, (*f*) other hoisting engineers, calling them to duty if the fire is near the shaft or slope bottom.

5. The fire-fighting crews will get water or chemical extinguishers on the fire as rapidly as possible.

6. If it is any kind of a fire except a small gob fire (in a gassy mine there are no exceptions), the mine foreman or the senior official in the mine should send messengers to withdraw all men from the mine except those needed to fight the fire.

7. The fire should be fought direct with water, chemicals, or rock dust as long as progress can be made.

8. The ventilation should not be altered or reversed unless life is involved, and then only if it is reasonably certain that men will

be able to escape and will not be caught by the reversal. If reversal is to be made, it must usually be within 10 or 15 minutes after the fire starts. Later is generally too late. The fan should be stopped or the air current reversed only when the man officially and legally in charge authorizes it.

SEALING A MINE FIRE

9. If the fire is getting beyond control by direct fighting, it must be sealed. The best method of sealing a mine fire is much in dispute.[77] Necessarily the conditions govern the procedure, but the writer, from experience and from observation, recommends the following general plan:

(*a*) If the fire is in a nongassy mine and the return from the fire does not contain a dangerous amount of inflammable gas, as indicated by safety-lamp tests or preferably by gas analysis, the fire area should be surrounded with temporary stoppings. The return should be left open until the rest of the temporary stoppings are erected. Two mine officials, using approved self-contained breathing apparatus or approved all-service masks, should be stationed in or near the return to test constantly with safety lamps and take samples of air for analysis. If a dangerous amount of inflammable gas is indicated as the intakes to the fire are gradually shut in, one of the intakes should be reopened and procedure continued as for a gassy mine, as follows:

(*b*) In sealing a fire that is beyond control in a gassy mine, temporary stoppings in the form of ventilating doors should be installed simultaneously in the principal intake and return, the doors being left off and the frames being made large enough not to restrict the ventilating current. Meanwhile constant testing should be done to determine if the gas in the return current is reaching such dangerous proportions as may require withdrawal of all men from the mine.

(*c*) While the temporary stoppings or doorframes are being erected, heavy rock dusting should be done, both inby as near the fire as feasible and outby as rapidly and thoroughly as possible.

(*d*) When the temporary stoppings have been erected, including the frames in the intake and those in the return, the doors should be so hung by hinge, rope, or chains from the top of the frame as to swing shut with the normal direction of ventilation but should be kept open by props or catches.

(*e*) If the gassy conditions are very threatening, each door should be held up against the roof or timber by passing a light rope or chain attached to the edge over a pulley or in lieu of that over a

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[77] Ryan, J. T., "Fighting and sealing fires in gassy coal mines": American Min. Congress, May 27, 1926. Paper gives replies of 67 persons to a questionnaire on the subject.

2 or 3 inch pipe wedged from rib to rib near the roof. A keg or tub holding 20 gallons or more of water should be used as a counterweight; filled with water it will hold up a hinged door made of double-matched boards and measuring about 6 by 7 feet. A quarter-inch hole should be bored in the bottom of each of the duplicate tubs, but this hole should be kept corked until all is ready.

(*f*) When the door stoppings are ready, as well as other temporary stoppings that are necessary to inclose the fire but do not affect the volume of intake or return appreciably, the corks should be pulled out of the tubs, which would be resting on the floor, and all the men withdrawn from the mine.[78]

(*g*) If the doors would block or shut off a split of air, as they usually would, probably it may be advisable to open another door between the intake and return, but farther outby, as the men withdraw.

(*h*) If no explosion occurs, 4 to 6 hours should pass before an examination is made; the time should depend upon the proportion of inflammable gas in the return just before the men were withdrawn.

(*i*) If an explosion does occur, the rescue and recovery crew should make an investigation as quickly as possible before gas has again accumulated. Meanwhile the return from the mine should be analyzed at short intervals. If conditions are not bad, resealing may be attempted farther out from the original fire. Otherwise it may be necessary to seal the mine openings.

(*j*) If no explosion results, permanent stoppings should be erected, with air locks for future investigation, by crews wearing self-contained breathing apparatus. Pipes with valves should also be put in all the principal stoppings at top and bottom, so that samples of gases can be collected for analysis.

(*k*) In a nongassy mine the stoppings should be placed as close to the fire as possible. Fires in a nongassy mine generally do not produce aftergases that are inflammable, but under some conditions of restricted air supply due to falls, they may produce carbon monoxide and unburned distilled hydrocarbon gases.

(*l*) The writer believes the preliminary stoppings in a gassy mine should not be placed too close to the fire, but 300 to 1,000 feet back,[79] to give time for erection of the door stoppings before accumulation reaches the explosive point. While the stoppings are being erected a bituminous mine should be thoroughly rock-dusted from the fire to prevent a possible gas and coal-dust explosion.

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[78] Rice, G. S., and Jones, L. M., Methods of Preventing and Limiting Explosions in Coal Mines: Tech. Paper 84, Bureau of Mines, 1915, 45 pp.

[79] Opinions differ on this distance of temporary stoppings from the fire, as is indicated by the answers to the questionnaire of J. T. Ryan. (See footnote 77.)

(*m*) Sealing a fire in a gassy mine is always hazardous. as shown by the recent explosion in the Horning mine, Pennsylvania, and by many others. The sealing should be done with the greatest care, and the effect of every detail should be considered.

(*n*) Sealing the entrances to a mine is the last resort and may involve suspension of mining for months, for so much air is inclosed the fire will burn a long time. If the coal bed is above water level or subsidence cracks extend to the surface, enough air may leak in to supply the fire indefinitely. Fires of this sort have lasted for years in the anthracite district of Pennsylvania and in the Rocky Mountain fields. Flushing in sand and silt is efficacious when conditions favor it. Steam, carbon dioxide, and sulphur fumes forced into the mine have all been tried with more or less success, but many fires have had to be extinguished by direct fire fighting, the fighters using self-contained breathing apparatus and establishing successive air locks to get near to the fire so that they could use water or erect air-tight seals around the seat of the fire.

(*o*) When a fire has been sealed off tightly, combustion rapidly reduces the oxygen content of the sealed area below about 10 per cent and correspondingly increases the content of carbon dioxide; the flames are extinguished, but slow combustion continues until the oxygen is virtually gone. Carbonaceous strata also absorb oxygen without perceptibly heating; this reaction accelerates the elimination of oxygen. When the oxygen has virtually disappeared the hot coals remain and will burst into flame if fresh air is brought in by restored ventilation. If a fire has burned long there may be a large mass of hot coal, perhaps more or less covered by ash and falls. An extreme example is the fire at the Majestic mine,[80] Illinois, where Bureau of Mines men, wearing self-contained breathing apparatus, made an exploration before opening a sealed fire area. The fire was buried under heavy falls of roof and was not detected, although passed over. When the air current was restored the fire revived and the coals had to be dug out and removed.

Another still more extraordinary example was a severe fire caused by an explosion in a mine of the Dering Coal Co. in southern Illinois. When efforts to extinguish the fire had failed, the shafts were sealed and water was run into them until it was high above the level of the mine workings. After the water was pumped out burning coal was found in "raise" workings where the pocketed air and gases had prevented the water from reaching it. The fire was then extinguished by direct fire fighting.

(*p*) The injection of steam into sealed fire areas has been tried extensively in the Pennsylvania anthracite district and in the iron

[80] Williams, R. Y., "Extinguishing the Majestic mine fire": Mines and Minerals, vol. 32, January, 1912, p. 342.

mines of the Lake Superior district. The amount of water from the condensation of the steam is relatively small. Doubtless the chief result accomplished by the use of steam is the creation of pressure within the area; this pressure would prevent air from leaking in past seals or through cracks in the strata.

(*q*) Carbon dioxide and sulphur dioxide have been used for fire fighting. It is claimed that the former has sometimes been successful. Like steam, its chief function seems to be to exclude fresh air from entering when the seals are not tight and to replace oxygen when the seals are fairly tight. Sulphur dioxide was used at a fire in a mine at Ziegler, Ill.; this gas was made at the mine and injected through a pipe. Its use was not considered successful. For one thing, too much oxygen entered with the gas. Carbon dioxide generated at the mine from limestone was used at a fire in the Grey Creek mine, Colorado, but failed, it is thought, because of subsidence cracks which admitted air. Liquefied carbon dioxide brought to the mine in tanks has been used at numerous metal-mine and coal-mine fires. It is claimed to have been successful in some instances. The use of carbon dioxide as "snow" for direct fire fighting has been noted on page 112.

(*r*) The writer does not believe it pays to inject inert gases if the fire seals are practically tight, but they may be helpful where tight sealing is impossible.

RECOVERING A SEALED FIRE AREA

10. The procedure incident to recovering a sealed fire area may include the following steps:

(*a*) Gases from different stoppings surrounding a sealed area should be sampled at regular intervals. If the seals are reasonably tight and the area is not extensive or does not embrace the whole mine, the oxygen content will gradually be reduced to 1 or 2 per cent within a week. In less perfectly sealed or in large areas a month or more may pass before this stage is reached. When there is leakage, there is a constant "breathing" of the area, due to barometric changes. Even though the fire stoppings are tight, coal pillars are more or less permeable to gases along bedding planes and joints or faces. When a sample of the inclosed atmosphere is taken, the inward or outward pressure should be observed by means of a water gauge; if there is leakage inward when sampling is done it may be necessary to discard the analysis. Meanwhile, carbon dioxide and hydrocarbon gases will be supplanting oxygen, and the analysis will show an apparent increase in the nitrogen of the inclosed air, because of the absorption of oxygen. Carbon monoxide, which may constitute 1 to 4 per cent of the atmosphere in the area when the seal is completed, will gradually decrease until the active fire is out. Experience has indicated that the rise or fall of carbon monoxide content is the best index of the state of an active fire. The entire absence of carbon monoxide does not prove that a fire is out, but its presence is a reasonable indication that active fire continues.

(*b*) When the oxygen content has been less than 3 per cent for some days, when no carbon monoxide appears in the analysis and when other conditions are right (for example, if the temperature is normal), persons wearing self-contained breathing apparatus should explore the fire area.

(*c*) If air locks were not made in the permanent seals, as they should have been, they should be erected outby a seal before the latter is broken.

(*d*) The investigating crews should be thoroughly organized and consist of men experienced in the use of breathing apparatus. No recovery work of this character should be undertaken without at least two crews of five men each and a chemist to analyze gases; one crew should always be used as a relief crew.

(*e*) The advance crew should wear approved self-contained oxygen breathing apparatus and have other approved appliances, such as electric lamps, safety lamps, a Burrell gas detector, a carbon monoxide detector, etc.[81]

(*f*) A small sealed area may be entirely traversed in one inspection, but generally the erection of a new stopping with air locks closer to the fire is required; moreover, it will probably be necessary to erect temporary ventilation stoppings in crosscuts and branch entries. Such stoppings will have to be built by men wearing oxygen breathing apparatus, but when the previous seal has been opened and ventilation advanced the more permanent seals can usually be erected by men wearing less cumbersome approved all-service masks, as there probably would not be a material deficiency of oxygen. In any case the presence of enough oxygen (18 per cent or more) would be indicated to the mask wearers by the continued burning of an approved flame safety lamp, which the leader of each squad should carry in addition to electric lamps.

(*g*) The fire area would be reached by successive steps if the foregoing program was carried out. If fire or hot coals are found water lines should be extended so hose can be played on the fire or portable extinguishers used before an air current is admitted. Carbon dioxide snow, already referred to (p. 112), would be an excellent cooling medium and would not cloud the atmosphere; steam is evolved when water is thrown on hot coals.

[81] Mine Rescue Standards, a Tentative Study: Tech. Paper 334, Bureau of Mines, 1923, 44 pp.

Parker, D. J., McCaa, G. S., and Denny, E. H., Self-Contained Mine Rescue Oxygen Breathing Apparatus: Bureau of Mines, 1923, 120 pp.

(*h*) Care should be taken on the removal of seals in reventilating a former fire area, so that any accumulated inflammable gases will not be drawn over possible concealed smoldering fire; the direction of the ventilating current should be so arranged as to force such gases into the return. Only a few experienced men should be in the mine when a fire area is being reventilated.

(*i*) Flooding a fire area is sometimes possible, but usually it can not be done, except in pitching beds, without flooding the whole mine. Flooding is generally effective, though costly, but consideration must be given to pockets that may hold air, such as in high caves or raises whose tops are not reached by the water. There have been several instances of fire being found in such high places after the mine was pumped out; the remedy is to bore holes to the high points to release the air or else to wait some months before pumping out the mine.

MISCELLANEOUS UNDERGROUND ACCIDENTS

ACCIDENTS FROM HAULAGE ANIMALS

Accidents caused by haulage animals (see Table 4) were responsible for 10 deaths in 1923, although the average annual number of deaths seems to be about six. Undoubtedly many more men are injured annually. The number of accidents from draft animals will decrease as mechanical haulage from the face replaces mules and horses. The change has been going on gradually. Most accidents caused by animals could have been avoided by keeping naturally vicious horses or mules out of the mine or by insuring better treatment of animals by drivers and stable men, who too frequently abuse mules or ponies, and greater watchfulness in handling them.

INRUSHES OF WATER AND SAND

Disastrous inrushes in coal mines in this country have been very rare in comparison with those in metal mines. Coal beds now worked in the United States are generally shallow, but very few except some anthracite mines in Pennsylvania are under bodies of water. However, in future there may be greater danger of inundation as mines become more numerous; also, unless better survey records of abandoned mines are kept on file by State inspection departments, there will be the possibility of striking into old unmapped mines that have filled with water. Great Britain has had many such flooding disasters because accurate surveys of old abandoned mines were lacking. One classic example in America was the inrush of surface water that flooded shallow longwall workings in the Diamond mine at Braidwood, Ill., February 16, 1883, and killed 69 men. In 1917, at Wilkenson, Wash., an inrush of water and gravel killed six men. There have been a number of such inrushes in the anthracite district of Pennsylvania, which perhaps offers the greatest hazards of this kind, but care in exploratory boring to determine the position of filled-in valleys and potholes in that district has undoubtedly prevented serious disasters.

PREVENTION OF INRUSH ACCIDENTS

The most important factor in preventing inrushes of water is the obtaining of accurate information on the presence of bodies of water overhead or in adjacent abandoned workings and keeping boreholes 20 to 50 feet in advance when such workings are approached, the distance depending on the probable pressure head of the water. Accurate maps should therefore be kept and filed by the company concerned and, when a mine is abandoned, by the State inspection department, so that at any future time knowledge may be obtained by a mining enterprise which proposes to begin development near by in the same or in lower coal beds.

Prevention of rushes of surface material requires care in laying out the mine and proper supervision of work. Another requisite is accurate information as to the thickness and character of the over-burden, especially where water may saturate overlying silt or gravel.

There have been many narrow escapes from mine inundations in various coal fields where flooded streams rose suddenly and the mine entrances had been placed too low. Obviously, such accidents can be prevented by filling in around the entrances to a level well above the high-water mark.

OTHER MISCELLANEOUS ACCIDENTS

Falling timber other than that incidental to falls of roof injures a large number of men, especially in the anthracite district. Such accidents occur mainly in pitching beds, where it is most difficult to maintain posts or props. Here, again, care in putting up the props and in subsequent inspection will lessen accidents.

Other kinds of miscellaneous underground accidents, like those caused by machinery, especially coal-cutting machinery, the use of hand tools, and falls of persons add a few deaths to the mortality roll annually and many more to the list of injuries. Some of these accidents, except those due to poor lighting, might occur just as readily on the surface as underground. There is no general remedy but care and close inspection by the company.

Many men are injured and some are killed by the undercutting chains of mining machines. To avoid these accidents the mining company must give special attention to safeguards on the machines and to instruction of the machine men. Permanently installed machines, such as underground hoists, can and should be surrounded with guardrails and fences.

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ACCIDENTS IN SHAFTS AND ALONG SLOPES

Shaft and slope accidents constitute only about 2 per cent of all mine accidents, and the largest number of these are caused by persons falling down shafts. This type of accident, with the rarest exceptions, seems entirely unnecessary and is usually due to not having proper fences and protection gates at the top, at landings, or on cages used for hoisting men, or else to the individual's failure to use them. As many as 27 men were killed by falls in 1920. It is desirable to make the guard gates of an upper shaft landing automatic, operated by the cage or skip. The ground landing gates can be made to lock automaticlly except when the cage is at the landing. Keps or rests should be used at the shaft landing when cages are used in hoisting men.

SAFETY MEASURES

Effective safety catches that will bring a cage to a stop, if the rope or coupling breaks, within 5 or at most 10 feet, should be used on all cages that hoist and lower men. The catches should be tested with a weight heavier than that of the largest number of men permitted to ride, as the State mining authorities may determine. Tests of the safety catches should be made at least once a month or at shorter intervals if the State requires.

Safety catches designed for operating on wooden guides usually are unsuitable for use on steel guides. The latter require special catches, or else special timbers may be necessary for the safety catches. Wooden guides should be made of wood that is not likely to splinter. Maple and oak are best, but carefully selected hard pine will do. Steel guides made from 75-pound rail or heavier make excellent guides where the water which may enter the shaft is not acid. In this case acid-resisting steel might be used.

In slopes where men are hoisted and lowered in mine cars or special man cars the hazard of rope or couplings breaking is usually greater than in shafts; ropes may become twisted and the wear is greater, especially if rollers and sheaves are not carefully aligned and kept in order.

Rubber-covered sheaves have been found effective in the deep inclined shafts of the South African gold mines, as the rope adheres well and does not slip over the periphery as steel rope that runs on iron rollers tends to do, with consequent cutting effect.

There are several designs for safety catches for use in steep slopes; these clamp on the rails but have been brought into general use.

Safety man cars have been used in slopes less than 45° These include one car whose wheels are placed on hinged pedestals at such an angle that when the rope or coupling breaks they fold back, and the body of the car drops on the ties, steel spikes in the bottom of the car preventing it from skidding.

In slightly inclined slopes a special drag-point truck is placed at the lower end of the trip, so that the "drags" will jab into the ties or bottom if the rope or coupling gives way.

Injuries to persons struck by cages or skips in shafts or by trips of cars on slopes constitute another accident item which seems unnecessary, yet 2 to 10 men have been killed in this way each year. The man injured or killed is usually trying to look up or down the shaft or slope as the cage or trip passes him. Deep refuge holes should be provided for men who have to repair or inspect slopes in slope mines. If slopes are regularly used for travel by men there should be a separate compartment for those who walk.

Overwinding has caused serious accidents. Detaching hooks were formerly used, but the present use of automatic control and brake devices on hoisting engines has virtually eliminated casualties from overwinding.

Accidents from the breaking of hoisting ropes in coal mines have become almost absent because of the high quality of rope supplied by makers and the prompt replacement of worn-out material by operators. From 1917 to 1924, inclusive, only five persons were killed in coal mines by reason of the breakage of cables. The safest rule is to replace a rope used for hoisting and lowering men when it shows wear and a number of breaks appear in individual wires. Frequently such a rope can be utilized for hoisting or lowering material.

SPEED OF HOISTING AND LOWERING MEN IN SHAFTS AND SLOPES

Rapid hoisting is not only dangerous but extremely uncomfortable and affects the morale of men by causing nervous shock. There is little excuse for rapid hoisting or lowering in the comparatively shallow coal mines of the United States.

The speed of hoisting or lowering men is regulated by many of the State laws and ranges from 600 to 900 feet a minute. This rate usually is held to represent the average speed from top to bottom, including acceleration and slowing, so the speed in the middle is much greater; however, the rates of acceleration and of slowing down are the objectionable features and should be kept under careful control.

In hoisting and lowering men most of the time is taken in getting them on and off the cages. In large collieries double-deck cages, where permitted by State authorities, greatly increase the speed of handling men, especially if double unloading and loading platforms at top and bottom are provided, as in many deep metal mines and in deep European coal mines; in such mines three or four decks sometimes are used and are loaded and unloaded simultaneously.

The maximum speed of hoisting can be controlled automatically by the hoisting-engine mechanism, but with adequate supervision such control should not be necessary in mines less than 1,000 feet deep; most coal-mine shafts in the United States come within this figure.

Handhold rods or chains on cages are psychologically useful if not strictly necessary when the cages have good gates and the men are lowered carefully and steadily, but the speed should not exceed 1,000 feet per minute. The speed of hoisting or lowering men is more difficult to control in slopes than in shafts. Usually a greater speed is allowed in slopes than in shafts, but there, too, it should not exceed 10 to 12 miles per hour.

SHAFT-HOISTING SIGNAL DEVICES

The modern standard devices for hoisting signals are electric bells and pneumatic gongs; both are good. They should always be supplemented with telephones that afford direct communication from the hoisting engine to the several landings. Another praiseworthy device is the electric flash signal so generally used in German coal mines and in this country in metal mines that have a number of levels from which hoisting is done.

On account of the length of hoist, slope hoisting signals are usually limited to electric bells, and telephone hoisting signals vary so much in different States that no standard set of signals can be formulated at this time, desirable as it would be to have a universal code. Only three signals seem to be universal; these are:

One bell, hoist coal or rock; also for men after man signal has been given from below and answered by the hoister man.

One bell, stop immediately when cage is already in motion going either up or down.

Two bells, lower empty or with material; also for men when man signal has been given from upper landing and after reply is received from hoister man.

Other signals should cover men who want to be hoisted or lowered.

Multiplicity of bell signals is undesirable to-day because a direct telephone serves much better for such other signals as fire, start pump, and stop, start, or reverse fan.

In conclusion, it is believed that accidents in shafts and slopes are largely preventable. Daily inspection of all hoisting mechanism is vital, and records of its condition should be kept by designated persons.

SURFACE ACCIDENTS AT COAL MINES

Accidents that happen on the surface in connection with the operation of mines are usually included in the total of mine accidents. In coal mining they represent 6 to 10 per cent of all accidents in and about the mines. This means a considerable hazard, although not nearly so great as that underground, since but 18.3 per cent of the total are employed on the surface. In most years the mortality rate of those employed on the surface is lower than one per thousand. The number of deaths from surface accidents shows a gratifying decrease in recent years. For example, in 1917 there were 261 deaths, whereas in 1924 there were only 138 and in 1925 only 127. The ratio of the number of injuries to the number of deaths is not known.

As will be noted in Tables 1 and 4, mine cars and mine locomotives cause the largest number of accidents. The number of mortalities from such accidents varied from 71 killed in 1919 to 24 in 1925. These deaths evidently occurred chiefly in drift and slope mines, at many of which there is a long haul on the surface from the mine mouth and yard to the tipple. The proper layout of mine yards and adequate safeguards, such as fences and guards, automatic switches, derailing switches, safety blocks to provide against cars and trips running away, and trolley wires and hangers with ample overhead clearance, would lessen such accidents appreciably. Individual care, however, is probably the most important means of prevention, hence educational work in safety should be carried on.

Another class of accidents at mining plants includes those where men are run over or crushed by railway cars or locomotives. The number so killed each year ranges from 16 to 36. Many of the accidents are due to letting cars loose to run down the yard without ample warning being given. Some system of automatic electric bells might be arranged at switches and 200-foot blocks to give warning. Another cause of such accidents is the cramped arrangement of the tracks and lack of enough room between tracks and between the cars and the mine tipple posts and chutes, especially at old mines.

Accidents from machinery form another important item in the classification of surface accidents. The annual number of deaths caused by machinery has ranged from 46 in 1917 to 8 in 1925. The great decrease in accidents of this type is probably due to better guards around machinery as well as to generally better care. It is probable that the injury rate is relatively higher than the mortality rate.

Many types of surface accidents not included in the foregoing might happen around any power or industrial plant; their occurrence is largely due to lack of care of the individual or to inadequate warning of danger. However, many accidents are due to poor layout, insufficient guards around machinery, runways in bad condition, and stairs without rails, so surveys to determine such deficiencies should be made by the mine management.

ACCIDENTS FROM SURFACE INFLAMMATIONS OF COAL DUST

Rarely persons have been killed or burned by the inflammation of coal dust, ignition occurring when men using open-flame lamps were cleaning out bins. There have been several instances of runaway trips in drift or slope mines stirring up a cloud of dust which was ignited by a burning stove that was knocked over, or by some unknown agency—possibly electricity or open lights.

In another instance coal dust was ignited by a hot bearing in a bucket elevator. In still another, a steam shovel was digging into an old dirt pile containing coal, when a slide raised a cloud of coal dust that ignited from the boiler fire, and the resulting inflammation of the dust killed a man. In a recent accident an unhoused motor in a dusty chute and screen room ignited a cloud of dust; the inflammation extended down the intake and became an explosion in the shaft bottom. A number of men were severely burned, and one man in the shaft bottom was killed.

In such accidents there is ordinarily rapid inflammation of coal dust rather than an explosion, a term that implies violence. Coal dust, unlike some cereal dusts such as starch dust, requires confinement to develop violence; nevertheless, the inflammations are just as dangerous to persons in their path, for the flame may be breathed and the burning dust sticks to the clothing and flesh, causing fearful burns. Inflammations of coal dust must, therefore, be guarded against, even though they are infrequent.

First, there is no need of excessive dust in the air of tipples and screen rooms. Conveyors and crushers, if used, should be completely inclosed. In such plants at French and German mines a vacuum system of dust collection is generally employed, and hoods are installed over the places where most of the dust arises.

Second, motors in dusty places should be inclosed and if possible should be flame proof; switches should be inclosed or of a permissible type; electric lights should always be of incandescent type inclosed in vapor-filled globes, the wiring should be carefully installed, and finally all open lights and the carrying of smoking tobacco or matches should be forbidden.

ORGANIZATION, ADMINISTRATION, AND REGULATION

Good organization, capable administration, and strict regulation are factors which probably cover at least one-half of all measures for preventing mine accidents. Adequate layout of the mine, including appropriate mining methods, and the use of approved machinery and materials perhaps represent one-fourth of what may be accomplished, and the care of individual miners and mine laborers for their own safety and that of their fellow workers possibly covers the remaining fourth of what may be done to prevent mine accidents.

To expect that coal-mine accidents can be wholly eliminated or even reduced to the same accident rate as in surface industrial plants is impossible; but at least, if all were done that could be done, coal-mine accidents could be reduced one-half. That such reduction is possible as shown by the European coal-mine industry, especially in Belgium and France, where the natural hazards are much greater than in mines of this country, because the workings are very deep, roofs weak, and larger amounts of inflammable gas are encountered. European methods admittedly increase costs, especially those caused by very close timbering, filling with rock or sand for the control of the weight of roof, taking out of a minimum amount of coal on the advance, and limiting the use of electricity in gassy mines. The former are necessary for the conditions that prevail; the latter are less necessary when suitable precautions are adopted.

Moreover, it is unnecessary to go abroad for comparisons, except for comparison of averages by countries. There is quite as wide a difference in the accident rates between our best planned and organized mines and those poorest organized as there is between the average of this country and that of certain European countries with the lowest accident rates.

ORGANIZATION AT COAL MINES TO PREVENT ACCIDENTS

Organization at coal mines to obtain the best results in preventing accidents must include:

1. Proper grouping of personnel.
2. Good engineering, including the development of the mine under definite instead of haphazard plans and the making of precise maps.
3. An adequate underground staff, so that every man may be visited four times in a shift.
4. Concentration of mine workings to avoid isolated workings and sealing off of those parts of a mine not in use for a long period.

5. Purchase and proper installation of the safest machinery possible, including permissible machinery and materials.

6. Proper layout of a mine in all its details to insure good ventilation at the faces, and in gassy mines isolation of return airways as far as practicable. The returns should, however, be inspected regularly and kept in repair.

7. Organization of mine rescue teams, with efficient approved equipment, to carry on rescue and recovery work after explosions and to fight mine fires occurring under any conditions.

8. Organization of first-aid classes for proper care of injured. This measure is not only humanitarian but also serves to develop the character of the mine workers. Adequate surgical hospital service should supplement first-aid work.

9. Encouragement of proper housing of employees and welfare work, as content and good health are important factors in accident prevention.

10. Establishment and maintenance at each mine of local mine safety associations, to be composed of all officials and representatives of th different classes of employees and to meet at least once each month. At these meetings reports on matters of health and safety should be submitted and discussed and action taken to prevent the recurrence of any fatalities and injuries that may have happened since the last meeting. This organization if efficiently conducted will sustain interest and insure joint cooperative effort by all officials and employees in promoting health and safety. Rewards or medals will stimulate efforts.

11. Placing such an organization in charge of a carefully selected official who is fitted temperamentally and is thoroughly interested in the work. He should encourage the employees to take a leading part in the organization. If the mining company is large enough to permit it, he should have no other duties and should be given standing by the company to command the highest respect. In one company a vice president and director was given charge of such organization.

12. As a most valuable adjunct, encouragement by the company of the establishment and maintenance of a mine community safety activity, such as advocated by the Bureau of Mines through the work of the Joseph A. Holmes Safety Association. This association was formed after the death of the first director of the Bureau of Mines, who led the movement for the establishment of the bureau. The association is made up of representatives of national institutes and organizations concerned in various branches of the mining and metallurgical industries. It encourages the establishment of local chapters and annually awards medals for deeds of heroism in the mining industry. A community organization will include in its

membership all persons employed and their wives and families, all working in a joint cooperative effort for the promotion of health, the advancement of safety, and the prevention of accidents in the mine and in the community. It serves to promote the morale of employees and encourage younger men to study for positions as mining officials.

13. Advertising to miners and mine officials and their families health and safety through the use of bulletin boards, lectures, motion pictures, mine rescue demonstrations, first-aid contests, contests among mines, or groups of mines, to establish the lowest accident rates, athletic events, placards, and records of unsafe practices of officials and workmen posted at working places.

MINE RESCUE AND FIRE-FIGHTING ORGANIZATION

CREWS—TRAINING AND APPARATUS

This bulletin deals with accident prevention rather than rescue and recovery work after explosions and mine fires. As it is, however, inevitable that such accidents (especially fires, which may be of spontaneous origin) will occur, the organization of such work at mines and the assistance given by State and Federal agencies are briefly discussed here.

Until recent years recovery work after explosions and fires was extremely hazardous, and in the quarter century preceding the last decade probably hundreds of rescuers heroically sacrificed their lives. After disasters men spurred on by the entombment of relatives and friends rushed into mines without equipment, frequently without considering the need of restoring ventilation or planning what they were going to accomplish. Far too often they carried open-flame lights into workings where inflammable gas might be encountered. Second explosions thus caused have, in a few instances, killed more men than the first explosion.

FEDERAL MINE RESCUE ACTIVITIES

One of the first activities of the Bureau of Mines, then under the leadership of the late Joseph A. Holmes, was to introduce the use of self-contained oxygen breathing apparatus and to assign men to undertake the development of better types of such apparatus and the standardization of mine rescue work.

Mine rescue stations were then established at certain points, and movable rescue stations—specially equipped railroad cars, manned by experienced engineers and miners trained in the use of breathing apparatus and first aid to the injured—were assigned to different mining regions.

At present the bureau maintains 10 such mine rescue or training cars and 10 rescue stations equipped with rescue trucks, serving all parts of the country where metals, coal, and other minerals are mined. The bureau has trained nearly 40,000 miners and mine officials in the use of breathing apparatus and awarded them certificates of proficiency. Rescue procedure, mine-fire fighting, and recovery work have been so systematized[82] that in recent years such work, when conducted by the bureau, has involved no loss of life.

However, the policy of the bureau has never been to have members of its staff attempt to act as life-savers and fire fighters for the mining industry of the country, but primarily to have its mine rescue and first-aid employees serve as teachers of rescue methods, fire fighting, and first aid. This program was initiated and is continued in the expectation that the industry or each State will establish its own mine rescue organization. The bureau would then only help to standardize methods and equipment.

STATE MINE RESCUE ORGANIZATIONS

Following the Cherry mine disaster of 1909, Illinois established rescue and first-aid training stations and subsequently tried the use of mine rescue railroad cars. Ohio and West Virginia have also established rescue and first-aid stations. In work at large mine disasters these State stations have cooperated with the Bureau of Mines.

LOCAL AND CENTRAL MINE RESCUE STATIONS

The Bureau of Mines has consistently recommended to mining companies the establishment of rescue stations, preferably central rescue stations, where rescue trucks could reach each of the mines it serves within about one-half hour and where a trained crew or a trained foreman would be in constant attendance and prepared to respond to a telephone call. The most important time in such work is usually the first hour. For subsequent recovery work experienced men will volunteer.

If an individual mine has many employees, it may be feasible for it to have its own rescue stations, with a foreman in charge, or to have a station supplemental to the central station.

The accident-insurance liability companies have given "credits" in fixing premium rates for the establishment of rescue stations, especially central stations, and in some States, notably Pennsylvania, many have been so established.

CHARACTER OF APPARATUS AT RESCUE STATIONS

One very important factor is to have all rescue apparatus of approved or "permissible" character and kept in readiness for immediate use.

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[82] Mine Rescue Standards, a Tentative Study: Tech. Paper 334, Bureau of Mines, 1923, 44 pp.

This bulletin can not discuss details, and the reader is referred to the numerous publications on self-contained mine rescue breathing apparatus and their use. Publications of the Bureau of Mines are as follows:

Development, care, and use

Paul, J. W., The Use and Care of Mine Rescue Breathing Apparatus: Miners' Circ. 4, 1911, 28 pp.

Parker, D. J., McCaa, G. S., and Denny, E. H., Self-Contained Mine Rescue Oxygen Breathing Apparatus: 1923, 120 pp.

Paul, J. W., and Wolflin, H. M., Rescue and Recovery Operations After Fires and Explosions: 1916, 109 pp.

Purposes and exhibitions

Wilson, H. M., National Mine Rescue and First-Aid Conference, Pittsburgh, Pa., September 23–26, 1912: Bull. 62, 1913, 74 pp.

Rice, G. S. (compiler), International Conference of Mine Experiment Stations, Pittsburgh, Pa., September 14–21, 1912: Bull. 82, 1914, 99 pp.

Manning, Van. H., Yearbook of the Bureau of Mines, 1916: Bull. 141, 1917, 174 pp.

Annual Reports of the Bureau of Mines for Years 1913, 1914, 1915, 1916, 1917, 1918, 1919, 1920, 1921, and 1924.

Permissible list

Howell, S. P., Ilsley, L. C., Parker, D. J., and Fieldner, A. C., Permissible Explosives, Mining Equipment, and Apparatus Approved Prior to March 15, 1922: Tech. Paper 307, 1922, 21 pp.

———, Permissible Explosives, Mining Equipment, and Apparatus Approved Prior to January 1, 1923: Tech. Paper 333, 1923, 22 pp.

Crawshaw, J. E., Ilsley, L. C., Parker, D. J., and Fieldner, A. C., Permissible Explosives, Mining Equipment, and Apparatus Approved Prior to January 1, 1924: Tech. Paper 364, 1924, 30 pp.

———, Permissible Explosives, Mining Equipment, and Apparatus Approved Prior to January 1, 1925: Tech. Paper 376, 1925, 35 pp.

Physiological effects and standards

Henderson, Yandell, and Paul, J. W., Oxygen Mine Rescue Apparatus and Physiological Effects on Users: Tech. Paper 82, 1917, 102 pp.

Bureau of Mines, Mine-Rescue Standards, a Tentative Study: Tech. Paper 334, 1923, 44 pp.

GAS MASKS

An important relatively new type of apparatus for secondary use in mine recovery and fire fighting is the Universal gas mask, a development from the military gas mask which, unlike the latter, can be used in the presence of less than 2 per cent of carbon monoxide; moreover, the canister absorbent will remove carbon dioxide and other toxic gases. The mask can not be used safely where the oxygen is depleted to the extent that a flame safety lamp will not burn. The mask is lighter and easier to use than a self-contained breathing apparatus, and while it should not be used for exploratory work like the latter it has a wide field of usefulness for follow-up parties or for use where the ventilation has been sufficiently restored to give at least 18 per cent of oxygen in the air.

An investigation into the use and limitations of use after explosions and fires was carried on by the Carnegie Institute of Technology and the Bureau of Mines, working in cooperation, by S. H. Katz, G. S. McCaa, both of the Bureau of Mines staff, and A. L. Barth, research fellow of the Carnegie Institute of Technology. Their report was published as Carnegie Institute Bulletin 14, Use of Carbon Monoxide Gas Masks in Mines, 1924.

Publications of the Bureau of Mines on the subject are:

Katz, S. H., Bloomfield, J. J., Fieldner, A. C., The Universal and the Fireman's Gas Masks: Tech. Paper 300, 1923, 22 pp.

Katz, S. H., and Bourquin, J. J., Comparison of Gas Masks, Hose Masks, and Oxygen Breathing Apparatus: Repts. of Investigations Serial No. 2489, June, 1923, 5 pp.

ADMINISTRATION

Administration covers the handling of the organization and the best use of mine facilities for the prevention of accidents. One defect in coal-mining administration in some companies is that their high officials, who are business men rather than mining engineers, do not visit the mines, are not acquainted with existing needs, and so may not support the operating officials in their requests for safety developments that require expenditure. The business heads should consider it a duty to make frequent visits to their mines and at least occasional trips underground.

The relations between the operating officials of the mine must be such as to encourage cooperation, discipline, and esprit de corps.

Discipline is so fundamental in its effect upon accident prevention and so self-evident that mere mention suffices. It is second only to proper organization in results.

Thorough mine inspection is one of the most important features of operating administration. In large companies it has been found best to have mine inspectors report only to the head operating official of the company. It is true that this arrangement sometimes causes trouble, as between underground operating officials and the inspectors, but encouragement of good fellowship will offset this. Meetings of the underground personnel at least once a week are highly desirable.

A bonus system for rewarding officials who have the best monthly records for prevention of accidents in a particular division or section has been found effective by certain large companies with low accident rates. Such awards should, perhaps, be based on the relative frequency of accidents which might have been prevented by good administration, rather than upon those caused by the victim's carelessness. Such distinction must be drawn by the management or a committee making awards.

To supplement the State inspection service, it would be a very good practice for mine operators in a district to interchange company inspectors two or three times a year—the reports of the inspectors to be held confidential. This interchange of inspection would tend to raise the accident standards of the cooperating mines gradually to those of the mine having the highest standard.

ACCIDENT-LIABILITY INSURANCE

Placing a money value on safety measures probably does not affect the attitude of mine operators who value safety methods and who desire to keep in the forefront, but it has a distinct positive value to the majority of mine operators by definitely showing that safety is not merely charity but is a definite economy.

Mine accident-liability insurance, with flat rates in different districts without reference to difference in hazards of the mines in that district, began many years ago. Such insurance merely spreads the risk without gain to accident prevention.

Liability insurance, with some selection of mines and limited inspection, was begun by operators' cooperative insurance companies about 25 years ago, when the compensation for death and injuries began to be assessed more highly by court decisions.

About 1913 the Associated Companies of Hartford undertook a plan of determining premiums for coal-mine accident-liability insurance after close inspection of mines and valuation of the relative hazards found in the respective mines. Subsequent inspections were to be made at regular intervals and the rates changed according to findings. Other liability-insurance companies followed the same procedure.

Later many coal-mining States enacted liability-compensation acts which standardized compensation for deaths and injuries and required payments to be made to the injured or to the families of those killed.

In 1915 Pennsylvania established a compensation rating and inspection bureau which has functioned admirably. The rates are $1.30 to $3 per $100 of pay roll, according to the relative hazard. The rating inspectors are separate from the regular mine inspectors, a plan that experience seems to show is best. Many other coal-mining States have now enacted laws for compulsory liability compensation insurance, but certain States which merely change flat rates have lost the great advantage of insurance compensation rating according to hazards determined by inspection and a schedule of risks. The coal-mining States need to standardize liability-insurance compensation.

In 1923 the United States Coal Commission investigated accident-insurance compensation. The report on this subject was made by H. M. Wolflin.[83]

The local officials of a mine are often so absorbed with their major problem, "getting out coal" and "getting it out cheap," that safety is often overlooked unintentionally. It is therefore of great advantage to the mine management to have independent inspection by the insurance companies or by State rating bureaus; undoubtedly this procedure has led to the adoption of many improvements to prevent accidents in mines.

The relative safety standing of a mine, as determined by its rating, on which the insurance premium is based, also brings the advantage of safety measures forcibly to the attention of mine operators.

MINE REGULATIONS

Regulations include both the mandatory regulations or laws of the State and the voluntary mine rules of the company concerned. Strict State mining laws, which are consistent and clearly worded, are highly important in accident prevention, not only because of their requirements but also because they raise the standard of the mining personnel and officials. Mining companies should heartily support movements looking to the improvement of State laws. Strict regulations put those operators who do not have good mining organizations and who are more indifferent to the best safety methods on the same basis, as to cost of producing coal, with those who voluntarily adopt the best safety practices.

State inspectors should be encouraged by mine managements to make the most rigid inspection of their respective mines, and State inspectors should be regarded as helpful friends rather than foes. Friendly cooperation is of the greatest value. The inspectors should be consultants on all doubtful or uncertain matters covering the interpretation of the law or on points which the law does not cover, especially in States where the regulations are imperfect or entirely out of date. Under such circumstances the mining men of the State should try collectively to bring to the attention of the legislature, commission, or mining department which may have the matter in charge the need of correcting regulations that have bad features. Some State laws include out-of-date clauses which handicap safety.

A few States have an industrial or mining commission which may issue new orders to meet changing conditions after a hearing has been held. This permits the formulation of consistent mining codes.

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[83] Wolflin, H. M., "The effects of compensation laws and differential compensation insurance rates on coal-mine safety conditions" U. S. Coal Commission Rept., part 3, Appendix 2, p. 1727.

Every State should have a large enough inspection force to permit every mine to be thoroughly inspected at least four times a year. The State should pay good salaries and place the inspectors under civil service to insure that thoroughly competent men be engaged and retained in office as long as they perform their duties properly. The system which prevails in Europe of having inspectors of different grades permits shifting of position and promotion and has many advantages.

Every mining company which aspires to better the safety methods in its mines must look beyond the minimum requirements of State regulations. Mine rules should be issued in small handbooks for distribution to all employees. The books must be carefully compiled to avoid conflict with the State regulations and especially to prevent any misunderstandings. The rules should be stated in as simple language as possible, and it is advantageous to have the rules formulated or divided for specific positions, beginning with the workers, as follows:

Underground employees

1. Miners.
2. Timbermen.
3. Trackmen.
4. Ventilation or brattice men.
5. Drivers.
6. Motormen.
7. Machinemen.
8. Mechanical loaders.

Underground foremen

9. Face bosses.
10. Fire bosses or examiners.
11. District bosses.
12. Assistant foremen.
13. Underground foreman or manager.

Surface employees

14. Tipple men.
15. Washery employees.
16. Yardmen.

Surface employees—Continued

17. Surface laborers.
18. Mechanics.
19. Hoisting engineers.
20. Fan attendants.

Surface foremen

21. Surface foremen.

Clerical force

22. Clerks and timekeepers (with reference to their help in emergencies).

Engineers and safety service

23. Mining engineers.
24. Safety engineers, inspectors, rescue men.

Mine management

25. Superintendent.

As far as is possible the duties of each group should be given, the name of the superior to whom the members of a group report, and for foremen the names of those who report to them.

To prevent mine accidents and to offset the possibility of the carelessness of one man affecting the safety of hundreds, good teamwork and a somewhat military organization with a minimum of red tape and a maximum of good fellowship is necessary to win the fight.

APPENDIX

Minimum quantity of air allowable and maximum number of men allowed on one split of air in the various States that have coal-mining laws [1]

State	Article or section of law	Minimum quantity of air allowable, cubic feet per minute per man [2]	Maximum number of men allowed on one split of air
Alabama	S. 40	100 [3]	Not mentioned.
Colorado	S. 110 and 113	100 [3]	100 in mines now opened (1925); 65 in mines or parts of mines opened hereafter.
Illinois	S. 14 *a* and *b*	100; 150 in gaseous mine	100; inspector has authority to order, in writing, separate currents for smaller groups of men.
Indiana	S. 10 *a* and *g*	100	75 or smaller number at discretion of chief inspector.
Kansas	S. 108	100	Not mentioned.
Kentucky	A. VIII; S. 1	100	60.
Maryland	Ch. XIV, S. 57 and 100.	100; 150 in gaseous mine	75; or, if impracticable, 100 by written order, or if in gaseous mine less than 75 by written order.
Michigan	S. 11	100; 200 in gaseous mine	100; 75 in gaseous mine.
Montana	S. 3501 and 3503	100; 150 in presence of fire damp	100 or less at discretion of inspector.
New Mexico	S. 3507 and 64(6)	100	Not mentioned.
North Dakota	S. 48 and 49	100; 150 in black-damp condition of mine or section of mine or as much more as may be necessary to keep section free from black damp.	75 or less at discretion of inspector.
Ohio	S. 922	150; 200 when fire damp present	Not mentioned.
Oklahoma	A. IV; S. 1 and 2	150; 200 in fire-damp condition [4]	45.[5]
Pennsylvania (bituminous).	A. IX; S. 1 and 2	150 in nongassy condition; 200 in gassy condition.	70 to 90.
Pennsylvania (anthracite).	A. X; S. 3 and 6	200 [6] [7]	75.
Texas	S. 2(*b*)	100 or increased at discretion of inspector.	100; inspector shall have authority to order splits for smaller groups of men.
Tennessee	S. 9 and 32	150 in class A mines liberating fire damp 100 in class B mines, dry and dusty; 85 in class C mines, fire damp and dust not present and more than 20 men employed; 85 in class D mines, fire damp and dust not present and less than 20 men employed.	50 unless impractical in mine inspector's judgment.
Utah	S. 60(*a*)	100; 150 in gassy mine	75.
West Virginia	S. 13, *f* and *g*	100 [4]	60; 80 in mine inspector's judgment.
Virginia	S. 1848 and 1852	100	60 in gaseous condition; 80 in mine inspector's judgment.
Washington	S. 27 and 28	100 and as much more as may be necessary to keep mine free from dangerous and explosive gases.	70; 90 in mine inspector's judgment.
Wyoming	S. 4431	150	50; inspector shall have authority to order splits for smaller groups of men.

[1] Compiled by Florence E. Harris.
[2] Allowance for animals where these are used ranges from 300 to 750 cubic feet per minute.
[3] If at any time the chief mine inspector or one of his associates finds that the air in any mine is not sufficient, he shall direct the operator to adopt such measures for the proper ventilation of said mine as he deems necessary.
[4] And as much more in either case as one or more inspectors may deem requisite.
[5] Does not limit this number to gassy mines but apparently is for all mines.
[6] And as much more as the circumstances may require.
[7] And in no case in mines generating explosive gases shall the velocity exceed 450 linear feet per minute

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INSTRUCTIONS FOR HANDLING— UNDERGROUND FIRES

In case of fire starting in the mines, the first consideration must be the safety of the men. When all have been accounted for attention shall then be given to the saving of property.

Discovery of Fire When fire is discovered in a mine opening—*First*, notify the nearest men and send them to warn others; *Second*, send some one to notify the engineer or cager or topman, giving number of nearest working place, if possible. (In calling the cage, give the emergency signal of nine bells on the buzzer.)

Duties of Engineer, Cager, and Topman The engineer, cager, and topman shall not leave their posts of duty until relieved. The topman must immediately have the stench released in the air line through the injector and have the Timekeeper notified of the fire. The topman shall be in charge until the Assistant Foreman has been located. The cager and engineer shall proceed to hoist the shift as soon as possible.

TELEPHONE AT ONCE!

THE TIMEKEEPER, on receiving the fire call and being given the name of the place where the fire is located, will CALL the following NUMBERS in ROTATION:

....	....	....	....
....	....	....	....
....	....	....	....

UPON RECEIVING AN ANSWER from the party called, the Timekeeper will say, "FIRE AT ....," and give the name of the place where the fire is located. Officials receiving fire call are not to ask the Timekeeper for additional information, but shall immediately repair to their respective divisions or departments and proceed under orders of the official in charge.

Direction Signs There shall be kept posted in conspicuous places at the intersections of drifts, signs showing the direction to be taken to reach other shafts or outlets to the surface.

General Notice All employees, when warned of a fire, must follow their respective stope or level leaders to the time office to check off. Foremen and Bosses also shall go immediately to the time office.

Safety Department The Safety Department will call out the reserve helmet men.

Oxygen Apparatus None but those holding certificates of training will be allowed to wear helmets. Men in helmets must not go farther than 500 feet from the fresh-air base, except on orders from the official in charge. These orders will only be given when lives are in danger.

Checking Men Shift Bosses, upon being assured that all men have received warning, will proceed to check their men at the time office. If a man is missing, search must not be made except under the direction of the Foreman or Assistant Foreman.

Special Orders When a fire is known to be burning in a division, no orders may be given for changes in ventilation or opening shaft station doors, other than for the starting or passage of blowers, except by the Mine Superintendent or General Foreman. Men passing through shaft station doors must see that doors are closed after passing through.

Water and Air Lines No changes shall be made in the water or air connections at the stations without notifying the Fire Department.

General Outline of Procedure

1. Notify nearest men and send them to warn others.
2. Notify hoist engineer or cager, giving place of fire. (In calling cage give emergency signal—nine bells—on buzzer.)
3. Release stench in air line at collar of shaft or portal of tunnel.
4. Notify Timekeeper, who will telephone to officials.
5. All men follow their respective stope or level leader to time office and await orders.
6. Shift Bosses check all men at time office. Search for missing men shall be made only on order of Foreman or Assistant Foreman.
7. Officials arrive and take charge.
8. Fire Department arrives with equipment.
9. Members of Safety Department arrive with trained helmet men.
10. Methods used will be decided on after officials arrive and fire is located.
11. All helmet men on duty will remain within call.

FIGURE 1.—Notice posted at shaft station as safeguard to miners