PROCEDURE IN SEALING AND UNSEALING MINE FIRES AND IN RECOVERY OPERATIONS FOLLOWING MINE EXPLOSIONS

REVISED MARCH 1938

By

J. J. FORBES and G. W. GROVE
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**Flooding mine fires**

- Use of incombustible barriers to prevent spread of fire
- Use of inert gas

**Unsealing mine fires**

- Factors governing time for unsealing
  - Extent and intensity of fire at time of sealing
  - Characteristics of burning material and overlying strata
  - Tightness of seals and enclosed area

**Influence of barometric pressure and temperature on enclosed area**

- Effect of ventilation on sealed area
- Sampling and analysis of atmosphere under seal
- Composition of fire gases in sealed area

**Typical examples of mine fires**

- Horning fire
- Oakmont mine

**Conclusions regarding time to unseal fires**

**Preparations for unsealing**

**Ventilation and rock dusting**

**Fan and fan attendant**

**Electric power cut-out**

**Methods of unsealing mine fires**

- Recovering sealed region by use of air locks
- Procedure used in unsealing Horning mine

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PROCEDURE IN SEALING AND UNSEALING MINE FIRES AND IN RECOVERY OPERATIONS FOLLOWING MINE EXPLOSIONS

By J. J. FORRES and G. W. GROVE

INTRODUCTION

This publication is a revision of the last of the series of four miners' circulars to be used in a course of training that will prepare mine officials to organize men for rescue and recovery work. The first of this series (Miners' Circular 33) discusses mine gases and methods of detecting them; the second (Miners' Circular 34) gives instruction in Bureau of Mines methods of sampling mine gases and use of the portable Orsat apparatus for analyzing air samples; the third (Miners' Circular 35) describes the methods and equipment used in protection against mine gases; and the fourth (the present publication) explains the procedure in sealing and unsealing mine fires and in recovery operations at time of or after fires or after explosions. This circular discusses organization, equipment and materials, and procedure in fighting, sealing, and unsealing mine fires, and in recovery operations following explosions; a practice problem for recovery procedure also is included. Although the data contained in this publication relate primarily to comparatively thin or medium thick coal beds with little if any pitch, it is believed that the procedure for sealing and unsealing mine fires, together with the principles and technique of identifying fire gases, is applicable, with modifications in some cases, to metal mines and coal beds, whether thick or thin and with varying pitches. This circular is a revision of Miners' Circular 36 issued originally in 1929.

ACKNOWLEDGMENTS

Acknowledgment for assistance in the preparation of this circular is made to D. Harrington, G. S. McCaa, C. W. Owings, E. J. Gleim, A. B. Hooker, and M. W. von Bernewitz, all of the Bureau of Mines. Acknowledgment is made to the Hillman Coal & Coke Co., Pittsburgh, Pa., and the Pittsburgh Terminal Coal Corporation, Pittsburgh, Pa., for permission to use maps and data relating to the Oakmont mine fire and the Horning mine fire and explosion.

1 Work on this manuscript completed January 1929; printed in 1929, revised and reprinted in 1938.
2 Supervising engineer, Safety Division, Bureau of Mines.
3 Mining engineer, Safety Division, Bureau of Mines.
PROCEDURE IN SEALING AND UNSEALING MINE FIRES

CAUSES OF MINE FIRES AND EXPLOSIONS

The basic cause of mine fires and explosions (except those due to spontaneous combustion and friction) is an igniting agent in contact with combustible material, explosive gas, or coal dust.

Combustible material, such as coal, timber, wooden doors, stoppings, mine cars, explosives, brattice cloth, and other combustible substances, together with explosive gas or coal dust or both, are present in most coal mines, some of them in virtually all underground noncoal mines as well; therefore, unless proper precautions are taken, a fire or an explosion is possible in almost any mine, and certainly no coal mine can be considered immune from fires or explosions.

The igniting agents of mine fires are electric arcs and sparks; open lights, matches, explosives (especially if blasting is done with black powder); ignitions of gas or coal dust, which, in turn, result in mine fires; and spontaneous combustion and friction.

The sources of ignition of mine explosions are electric arcs and sparks, open flames such as open lights, mine fires, matches, and blown-out shots (particularly if black blasting powder is used), and explosions of unconfined or improperly confined explosives.

Regardless of the type, it is necessary for the igniting agent to be in contact with combustible material to cause a mine fire, or with an explosive mixture of gas or a cloud of coal dust to result in an explosion. Therefore, a gas explosion is possible only if an explosive mixture of gas is permitted to accumulate and be ignited, and coal dust cannot explode unless enough is allowed to collect so that it can be ignited and propagate or extend flame and violence.

In recent years, probably 90 percent or more of the mine fires and 75 to 80 percent or more of the explosions have been ignited by electricity. Consequently, great care should be exercised in installing, operating, and maintaining electric wiring, machinery, and equipment, particularly at and around the face region in coal mines, because gas or dust or both are likely to be found there at any time.

In considering matters connected with those affairs, the principal objective of the careful, conscientious mine official should be to prevent mine fires and explosions by eliminating, so far as possible, sources of ignition and by preventing the accumulation of explosive gas and coal dust.

HAZARDS OF MINE FIRES AND EXPLOSIONS

Mine fires and explosions are an ever-present hazard; in fact, they are the greatest hazard that confronts officials and men in the operation of mines. They not only jeopardize the life of every man working in the mine but the lives of the men who participate in rescue and recovery work. In addition to the cost in human lives, the dollars-and-cents cost of mine fires and explosions is so great that they constitute a heavy tax on the organizations affected by them and one that is readily avoidable.

The most common hazards in connection with mine fires are the asphyxiation of men by smoke and fumes, often in distant parts of the mine as well as in proximity to the fire; injury or death of men by falls of roof while fighting, sealing, or unsealing the fire; or
ignition of an explosive mixture of gas or coal dust that may injure or kill underground workers. To those who must work on them, mine fires are far more hazardous than are explosions, as the explosion has usually done its harm while the mine fire may at any time cause an explosion or other untoward occurrence with possible death to those in the mine engaged in handling the fire.

Undoubtedly a mine fire in a dry, dusty bituminous-coal mine that is liberating explosive gas in or in the vicinity of the fire area is the most hazardous to combat and extinguish. There is not only the danger of a gas explosion but the greater hazard that even a small gas explosion may ignite coal dust, or a fall of roof may throw a cloud of coal dust into the air which may come in contact with the flame of the fire and produce a widespread and destructive explosion.

Fighting a fire in a gassy anthracite mine, involving several coal beds, also is extremely hazardous because of the danger of a gas explosion; there is also the possibility that highly heated poisonous gases may be encountered unexpectedly by those in the mine who may not be equipped to resist their harmfulness.

Fire in a metal mine generally is not as hazardous to combat as fire in a coal mine, because explosive gas is rarely found in metal mines and explosive dust is rarely a factor; however, the smoke, fumes, and gases given off by metal-mine fires usually are hard to handle because ventilation in many metal mines is inadequate and poorly controlled. Many metal mines depend largely or entirely on natural ventilation, which is stopped or even reversed when a fire occurs; and in any event, the lack of control of air flow in so-called naturally ventilated mines (coal or metal) is hazardous in the extreme when a fire occurs. If adequate mechanical ventilation, properly controlled, were maintained in metal mines, the hazards from fighting a fire would be substantially lessened.

The usual hazards of mine explosions are that men may be burned or otherwise injured or killed by the heat and violence of the explosion; that men may be affected, overcome, or killed by the gases resulting from the explosion; and that another explosion may occur, due to fires or smoldering embers, and injure or kill additional men. Undoubtedly mine explosions are most dangerous when bituminous or lignitic coal dust is involved. A coal-dust explosion, or ignition of explosive gas that later results in a dust explosion, may spread throughout the entire mine and even to the outside of the mine. Explosion of a cloud of fine bituminous or lignitic coal dust can occur without the presence of explosive gas, but a coal-dust explosion, ignited directly or by a gas explosion, will not propagate or spread if the mine is adequately and properly rock-dusted. However, if a dust explosion occurs and a mine is not rock-dusted or is only partly rock-dusted, the explosion may travel or propagate through most or all of the mine. An explosion involving explosive gas only also is extremely dangerous. However, the force of a gas explosion will be “local” or limited to an area required for the heated gases to expand; and, unless a fairly large body of gas accumulates, a comparatively small portion of a mine usually is affected.

It should be emphasized that without an efficient organization, suitable and adequate equipment and materials, and proper procedure, the hazards of mine fires and explosions will be increased greatly.
IMPORTANCE OF RESCUE AND RECOVERY OPERATIONS

The necessity of prompt and correct procedure to save live men who may be entombed, the safety of those engaged in the work, and the prevention, as far as possible, of additional property damage make rescue and recovery operations after mine fires and explosions extremely important.

Immediately following the occurrence of a mine fire or explosion, and probably for some time thereafter, there is likely to be excitement, confusion, and disorganization among the officials and workmen. Frequently little or nothing of importance is done, or wrong action is taken, with resulting needless loss of life of entombed men or of those engaged in rescue and recovery work. Naturally, when mine management and workmen are confronted with conditions that usually are entirely foreign to their experience, wrong methods are likely to be used.

Most mine officials have never had a disaster in their mine and their ordinary operating experience is of little value in controlling the abrupt changes that take place in and around a mine after a fire or explosion. Moreover, the official in charge may be greatly disturbed by the loss of subordinate officials, friends, and possibly relatives, and the general loss of life and property, so that his otherwise sound judgment and reasoning powers may be affected seriously.

The most important things for speedily, safely, and efficiently conducting rescue and recovery operations after mine fires and explosions are: (1) Efficient organization, (2) adequate and proper equipment, (3) sufficient materials, and (4) proper procedure in performing the work. All of these are highly essential and will be discussed in considerable detail.

The authors of this circular have had rather wide experience in assisting with and directing rescue and recovery operations following mine fires and explosions, and have included information on the most important or essential things to be done and how to do them.

ORGANIZATION

The necessity for a capable and efficient organization to carry on rescue and recovery operations after a mine fire or an explosion cannot be overemphasized.

The personnel comprising the organization should be of the highest type obtainable, well trained, and preferably with considerable experience in the duties they are to perform. To know what to do and how to do it and to apply such knowledge promptly often may save the lives of entombed men and prevent needless risk and possibly loss of life by men engaged in rescue and recovery work.

The numerous explosions and fires that have occurred in well-equipped and well-operated mines indicate clearly that much thought and consideration should be given at all mines to preparation for such emergencies. Lack of efficient organization after mine disasters frequently has resulted in loss of life and property and in unnecessarily prolonged recovery operations.

IN CASE OF COAL-MINE FIRE OR EXPLOSION

Notify Chief State Mine Inspector and District Mine Inspector

<table>
<thead>
<tr>
<th>Chief Inspector</th>
<th>Address</th>
<th>Telephone</th>
</tr>
</thead>
<tbody>
<tr>
<td>District Inspector</td>
<td>Address</td>
<td>Telephone</td>
</tr>
</tbody>
</table>

GENERAL ORGANIZATION AND PROCEDURE

SUPERINTENDENT:
Information Bureau.—Furnish information to press and others.
Guards.—Rope off and guard all mine entrances. Regulate traffic on roads leading to mine.
Mine Clerk.—Stay by telephone, preferably where the superintendent has established headquarters.
Have two men for extra duty.
Outside Foreman.—Provide information bureau, messrooms, emergency hospital, policemen, rest rooms, and sleeping quarters.
Supply Clerk.—Stay at your post. Provide the following for immediate use: Nails, brittle cloth, hatchets, axes, saws, picks, boards, props, shovels, illumination checks, electric cap lamps, flame safety lamps, telephone wires, and insulators, stretchers, and first-aid cabinets. Also provide for persons authorized by management: Overall, gum shoes, gum boots, gloves, caps, electric safety lamps, and flashlights. Record all equipment issued and returned.
Electrician.—Pull and lock immediately, whenever authorized by superintendent, all electric switches where electricity enters the mine. Provide material needed to carry any additional telephone communications.
Fan Attendant.—Stay at fan and see that it is running. Have machinist or electrician make any necessary repairs.
Foreman, Central Shop.—Send men, or go yourself, to assist machinist and electrician with fan or other necessary work. Appoint shopmen to stay in shops.
Check and Lamp Men.—(Stationed in lamp house with adjoining room.) See that each man receiving lamp has been approved by the superintendent. Record all equipment issued and returned. Give each man a check number; record his number and name in a book.

SUPERINTENDENT—Continued.

Final Check Men.—(Stationed within the roped-off area at each entrance.)
Allow no person to enter the mine except those authorized by the officials in charge.
Examine each man carefully for smoking articles and matches. Make no exceptions.
Check each man in and out by number and name; note time in a book. Note that each man is fully equipped for the work he is to do.

MINE FOREMAN.—Have fan inspected. Do not reverse ventilation except after consultation with all responsible officials present and after issuing written order.
Organize underground operations in cooperation with superintendent and with State inspector, when he arrives.

CHIEF ENGINEER.—Take to headquarters copies of maps showing regular courting of air, location of regulators, stoppings, doors, and pumps, substations, motors, and other machinery; also obtain maps of adjoining mines.

OTHER SUPERINTENDENTS AND FOREMEN.—Assemble your organization as per chart for immediate call. Stay by telephones of your respective plants until told to leave by general superintendent.

DIRECTOR OF SAFETY AND INSPECTION.—Assemble apparatus men; assemble first-aid men. Organize crews for their respective shifts. Arrange for: Rescue and recovery operations; emergency hospital; ambulance service; physicians; and Red Cross work.

NOTIFY AT ONCE IN THE ORDER NAMED

<table>
<thead>
<tr>
<th>General Manager</th>
<th>Director of Safety Department</th>
<th>Mine Superintendent</th>
</tr>
</thead>
</table>

MINIMUM EQUIPMENT FOR MINE RESCUE STATIONS

<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 self-contained oxygen breathing apparatus.</td>
<td>10</td>
</tr>
<tr>
<td>11 extra bottles, reducing valve.</td>
<td>11</td>
</tr>
<tr>
<td>Extra mouthpieces, breathing bags, etc., and 100 charges of recompressed material.</td>
<td>100</td>
</tr>
<tr>
<td>1 low-pressure gage.</td>
<td>1</td>
</tr>
<tr>
<td>1 oxygen pump with spare parts.</td>
<td>1</td>
</tr>
<tr>
<td>5 oxygen cylinders (100 cu. ft. capacity).</td>
<td>5</td>
</tr>
<tr>
<td>1 tool box with wrenches and other tools.</td>
<td>1</td>
</tr>
<tr>
<td>6 approved flame safety lamps and repair parts.</td>
<td>6</td>
</tr>
<tr>
<td>13 approved flashlights.</td>
<td>13</td>
</tr>
<tr>
<td>1 electric cap lamps.</td>
<td>1</td>
</tr>
<tr>
<td>5 approved all service gas masks.</td>
<td>5</td>
</tr>
<tr>
<td>1 dozen rubber boots.</td>
<td>12</td>
</tr>
<tr>
<td>16 extra suits.</td>
<td>16</td>
</tr>
<tr>
<td>10 self-rescuers.</td>
<td>10</td>
</tr>
<tr>
<td>1 thousand-foot lift line on a reel.</td>
<td>1</td>
</tr>
<tr>
<td>3 Great apparatus and means of taking air samples.</td>
<td>3</td>
</tr>
<tr>
<td>1 anemometer and 1 psychrometer.</td>
<td>1</td>
</tr>
<tr>
<td>3 canary birds and 1 CO detector.</td>
<td>3</td>
</tr>
<tr>
<td>1 brittle cloth, boards, nails, copper hammers, and 1 mine telephone and wire.</td>
<td>1</td>
</tr>
<tr>
<td>6 three-gallon fire extinguishers and fire hose.</td>
<td>6</td>
</tr>
<tr>
<td>1 oxygen inhaler.</td>
<td>1</td>
</tr>
<tr>
<td>1 first-aid cabinet complete.</td>
<td>1</td>
</tr>
<tr>
<td>13 woolen blankets.</td>
<td>13</td>
</tr>
<tr>
<td>1 set of splints complete.</td>
<td>1</td>
</tr>
<tr>
<td>1 Army stretcher.</td>
<td>1</td>
</tr>
<tr>
<td>1 list of apparatus men with telephone numbers.</td>
<td>1</td>
</tr>
</tbody>
</table>

BUREAU OF MINES SAFETY CARS AND STATIONS

The Bureau of Mines operates 11 mine safety cars and 11 mine safety stations.
In case of disaster, notify U. S. Bureau of Mines, at Experiment Station, 4800 Forbes Street, Pittsburgh, Pa., or at one of the following places:
- Birmingham, Ala. Salt Lake City, Utah.
- Denver, Colo. Seattle, Wash.
- Dubuque, Minn. Vincennes, Ind.
- Dallas, Tex. Wilkes-Barre, Pa.
- McAlester, Okla.

FIGURE 1.—Organization chart for coal-mine fires or explosions.
SURFACE ORGANIZATION AND PROCEDURE
FOR METAL-MINE FIRES

Remove Underground Workers Immediately
Notify State Department of Mines and District Mine Inspector

State Department of Mines: Address: Telephone
District Inspector: Address: Telephone

ORGANIZATION AND PROCEDURE

SUPERINTENDENT—Continued.
Final Checkmen.—Stationed within the roped-off area at each entrance. Allow no persons to enter the mine except those authorized by the officials in charge.
Check each man in and out by number and name; note time in a book.
Note that each man is fully equipped for the work he is to do.

MINE FOREMAN OR CAPTAIN.—Have fan inspected. Do not reverse fan except after consultation with all responsible officials present, and only after issuing written order. Organize underground operations in cooperation with superintendent and with State inspector when they arrive.

CHIEF ENGINEER.—Take to headquarters copies of maps showing regular coursing of air, location of lans, regulators, overcasts, stoppings, doors, pumps, compressors, substations, motors, underground hoists, and other machinery. Also obtain maps of adjoining mines.

OTHER SUPERINTENDENTS AND FOREMEN.—Assemble your organization as per chart for immediate call. Stay by telephones of your respective plants until told to leave by general superintendent.

DIRECTOR OF SAFETY AND INSPECTION.—Assemble apparatus men; assemble first-aid men. Arrange for: Rescue and recovery operations; emergency hospital; ambulance service; physicians; and Red Cross work.

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In case of disaster, notify U. S. Bureau of Mines, at Experiment Station, 4800 Forbes Street, Pittsburgh, Pa., or at one of the following places:
Birmingham, Ala. Salt Lake City, Utah.
Denver, Colo. Seattle, Wash.
Duluth, Minn. Vincennes, Ind.
Joliet, Tenn. Wilkes Barre, Pa.
McAlester, Okla. Dallas, Tex.

FIGURE 2.—Organization chart for metal-mine fires.
Organization for training personnel and for handling mine disasters may be classed as follows: (1) Preliminary, (2) temporary, and (3) permanent. By preliminary organization is meant the selection and training of officials and oxygen breathing-apparatus crews and the assignment of duties and procedure to be followed by local mine personnel in the event of a disaster; by temporary organization is meant the organization of officials, oxygen breathing-apparatus crews, and workmen connected with the mine at which the disaster occurs, with possibly some assistance from nearby mines, which immediately following a disaster carries out essential duties until the arrival of additional assistance; and by permanent organization is meant the organization of officials, oxygen breathing-apparatus crews, and employees from the local mine and from other mines and companies, State mine inspectors, employees of the Federal Bureau of Mines, and others to function until the recovery work is completed.

**PRELIMINARY ORGANIZATION**

Every mine should have an emergency organization of officials, oxygen breathing-apparatus crews, and other selected employees who are trained to take charge and immediately start recovery operations after a disaster. The need for preparing for emergencies such as fires and explosions is evident to those experienced in rescue and recovery work, as they often find at a mine after a disaster a highly disorganized personnel, total absence of necessary equipment and materials, and little or no effective effort being made to recover entombed men or to effect quick and properly safeguarded entry into the mine.

**ORGANIZATION CHARTS**

An up-to-date organization chart containing the names, addresses, and telephone numbers of State mine inspectors, local mine officials, and members of oxygen breathing-apparatus crews, officials of other mines and companies, the Federal Bureau of Mines, doctors, and others likely to be of aid is of much value following a mine disaster. The organization chart should contain also a list and the location of equipment and material required to start rescue and recovery operations. Copies of the organization chart should be posted in suitable places around the mine.

Figures 1 and 2 are plans of organization charts for coal and metal mines. Mining companies may use these charts to advantage (possibly with some modifications to fit local conditions) in training an organization for disaster work and in obtaining and maintaining essential equipment and materials. Copies may be obtained from the Bureau of Mines for posting at mines, in offices, etc. Where these charts are not applicable, they may serve as a guide for interested mining companies in preparing similar charts of their own.

Unnecessary loss of life of entombed men and of those engaged in recovery operations in many instances has been caused by lack of preparation and organization or improper procedure. Therefore, before a fire or explosion has occurred considerable thought and attention should be devoted to perfecting an organization to function satisfactorily if a disaster should take place.
Local mine officials, including surface officials, from time to time should receive instruction and training in the duties they are to perform individually and collectively should a mine fire or explosion occur in their mine. They should be informed where tools, brattice cloth, and other equipment and materials may be obtained quickly at the mine and from adjoining mines, jobbers, mills, hardware stores, etc. All officials should be instructed that in the absence of superior authority they are to attend promptly to the most important things and notify immediately, according to a list that should be kept available, all persons required to assist at a disaster, particularly the State mine inspector having charge of the district in which the mine is located, oxygen breathing-apparatus crews, doctors, the Federal Bureau of Mines, and others.

Members of oxygen breathing-apparatus crews should be selected carefully and should receive thorough training and instruction in the use and care of oxygen breathing apparatus and rescue and recovery procedure. They should be physically sound and fit to perform strenuous labor under oxygen and should have good judgment and a cool, calm disposition.

Additional training and instruction should be given frequently to the oxygen breathing-apparatus crews in an irrespirable atmosphere to insure that men and equipment are in condition for an emergency, and underground maneuvers, involving a recovery problem, should be conducted occasionally.

**TEMPORARY ORGANIZATION**

Until experienced help arrives and a permanent organization can be effected, a temporary organization composed of the local mine officials and employees should be formed.

In the event that most or all of the local underground officials have either been killed or imprisoned in the mine or for some other reason are not available immediately, the senior official outside, or some employee previously designated, should assume charge and form a temporary organization. The person who is in charge should confer promptly with all those present having mining experience, outline a plan of procedure, and perform other important duties, among which are the following:

**EXAMINING FAN**

After a mine fire or explosion, the mine fan should be examined and should be kept running (if in operation) and a man should be placed in charge to see that it is kept in operation. If the fan has been damaged or destroyed by an explosion, necessary repairs should be made immediately or another fan should be provided. The ventilating current should not be reversed without good reason and then only after due consideration and consultation; written orders should be issued by the person or persons responsible for reversing the ventilating current, and generally this duty should fall on a responsible official of the State or of the mining company.
CUTTING OFF ELECTRIC POWER FROM MINE

Electric power should be "cut off" immediately from the mine and remain off until it is definitely determined that having power in the mine will not create a hazard.

WARNING AND DIRECTING UNDERGROUND EMPLOYEES

In case of fire in a mine or mine entrance and after an explosion, an effort should be made to warn those within the mine. Telephones connected with the inside of the mine should be used for this purpose if they have not been put out of commission by the explosion or fire. A mine-fire alarm can be given to different parts of the mine more quickly by telephone than by any other means, except possibly by the stench alarm system for metal mines or other mines having a wider-spread compressed-air system. The telephone system, if one has been in use, may not be destroyed in all parts of the mine by an explosion; every effort, therefore, should be made to establish telephone communication with men in the mine to obtain, if possible, information regarding the disaster and to warn and instruct the men that can be reached. Outside telephone connections should be used to summon assistance and to order needed equipment and materials. A man should be stationed at all times at an outside telephone that also communicates with the inside of the mine.

PLACING GUARDS

Immediately after a mine fire or an explosion, guards should be placed at all mine entrances to permit no one to enter until orders have been given to explore the mine and to obtain a record of any men who come out of it.

Guards, preferably with police powers, also should be placed at roads and paths leading to the mine to protect and control relatives and friends and spectators who rush to the mine and to prevent interference with work. All persons not engaged in the performance of useful work should be kept as far as possible from the mine entrances as a precaution against injury or death by an explosion and in order to prevent interference with the rescue and recovery work.

Additional guards, or officers, should be assigned to keep the roads leading to the mine and the available space around the mine open. This is important so persons who have been called to assist in recovery work can reach the mine, and so that equipment, material, and supplies can be delivered.

State police organizations or highway patrols, or both, can be used to advantage in guarding entrances to mines and keeping roads clear; usually the services of these men can be obtained readily.

CALLING ASSISTANCE

All local employees not within the mine should be called to report at once, and, when the situation warrants, assistance should be asked of adjoining or adjacent mines and mines at distant points. The character of the assistance required should be indicated clearly. Oxygen breathing-apparatus crews and experienced mining men with
training and experience in rescue and recovery work will be of most value. Other persons who should be notified are: State mine inspectors (particularly the inspector in whose district the mine is situated), the county coroner, members of local and adjacent mine rescue crews, surgeons, and doctors in the vicinity of the mine, and the Federal Bureau of Mines.

A list of persons and organizations, with addresses and telephone numbers, should be kept posted near telephones so they may be notified without delay. A man should be in attendance at all times at the telephone used for outside communication.

**ROPING OFF MINE AREA**

As soon as possible after a mine fire or explosion, substantial ropes should be placed at some distance from the mine entrance for the safety of the crowds that collect; to exclude from the mine or its entrances relatives and friends of those who may be entombed and may be tempted to take unwarranted risks in trying to reach their men; and to prevent the curious from interfering with persons required to carry on necessary work.

After the area has been roped off, guards, or preferably officers of the law, should keep the space inside the ropes clear. Suitable tags or other marks, which should be kept visible at all times, should be provided for all workmen and others who have permission to enter the roped-off area. Only persons with the proper tag or mark in evidence should be permitted to remain inside the roped-off area.

**WARNING CONNECTING AND ADJOINING MINES**

Officials of mines known to be connected with or adjoining a mine in which a fire or explosion has occurred should be notified promptly, so that men working in the connecting mine may be removed.

Failure to warn promptly or to remove or prevent men from entering a mine connected with one in which a fire or explosion has occurred may cause such men to be affected or killed by poisonous or asphyxiating gases from the mine suffering such explosion.

Officials of adjoining mines, whose active or abandoned workings are in proximity to a mine in which a fire or explosion has occurred, should be notified also that they may take the necessary precautions to safeguard their underground employees.

**PREPARING TO ENTER MINE**

After the above and probably other important matters have received attention from the person in charge, or have been delegated to responsible, reliable, and competent persons, preparations should be made to enter the mine and start recovery operations. When experienced underground employees, fully equipped oxygen breathing-apparatus and gas-mask crews, gas-detecting devices, and other necessary equipment and materials are assembled and ready, recovery work should be started. Detailed information on conducting recovery work is given in the sections dealing with procedure following mine fires and explosions,
CHECKING IN AND OUT

Arrangements should be made to obtain the check numbers or names, or both, of any men who come out of a mine after a fire or an explosion. When recovery work is started, a reliable man or men should be designated to check men in and out of the mine, to search men going underground for matches, lighters, and smokers' articles, and to prevent any but permissible electric cap lamps and flashlights and properly assembled permissible flame safety lamps in good condition from being taken into the mine.

Each man who enters the mine should be given a numbered check. A record should be made of checks and names, with the date and hour of entrance and return to the surface. A check cabin or room should be established near the entrance of the mine but not in a direct line with the entry, and a man or men should be stationed there at all times to check men in and out of the mine.

PERMANENT ORGANIZATION

After the arrival of assistance, such as State mine inspectors, Bureau of Mines representatives, mine officials, oxygen breathing-apparatus crews, workmen from other mines and companies, and others, a permanent organization should be formed. The permanent organization should take over and carry on the work started by the temporary organization, perform any other necessary functions that might have been overlooked by the temporary organization, and complete the recovery work in the safest and speediest possible manner.

The kind of disaster (fire or explosion) and its extent (area involved, number of men entombed, killed, and injured) naturally will govern the size of the permanent organization and other necessary arrangements. In addition to the requirements indicated for a temporary organization, other important functions and arrangements are essential for a permanent organization. When a fairly large disaster has occurred, resulting in a number of fatalities that will require from a few to several days or more to complete the recovery work, the following and probably other arrangements for a permanent organization should be completed.

MAN IN CHARGE OF OPERATIONS

The permanent organization should be headed by a cool, competent mining man well versed and experienced in the technique of rescue and recovery work, preferably some person who has no relatives or very dear friends involved in the disaster. The man in charge should have complete authority, and while off duty or away from the mine he should delegate his authority to a selected person, so that someone who will be recognized as in charge will be available at all times. In addition to the man in charge of operations, there should be assembled an advisory committee of mining men thoroughly experienced in recovery operations, more or less conversant with local conditions, and also well versed in procedure and in the use and limitations of protective and detective apparatus and devices necessary for the safety of those engaged in the recovery operations.
A plan for the safe conduct of the work should be formulated by the man in charge and his advisory committee as soon as they have considered the situation and formed their conclusions. There should be no essential deviation from the plan as outlined unless such change is approved after careful consideration by those in charge.

The man in charge and his advisers should select from the personnel available the men who are to comprise the various underground shifts and the surface organization and should decide on the length of shifts.

If the recovery operations are extensive, involving a large mine or a large area, or progress will be slow due to extensive falls or other difficulties, so that days or even weeks may be required to complete recovery operations, the work should be arranged in suitable shifts.

Recovery work is hazardous, strenuous, and nerve-racking, therefore, the shifts should not exceed 8 hours at the most; in fact, best results often can be obtained by 6-hour or, in some cases, 4-hour shifts. Due consideration should be given to the type of work required, height of coal, degree of pitch, extent of destruction including fallen rock, and personnel available before deciding on the length of shifts.

UNDERGROUND ORGANIZATION

The personnel comprising the underground organization is of the utmost importance as the progress of the work, as well as the safety of all concerned, will depend on their knowledge and efficiency.

MAN IN CHARGE OF SHIFT

A man experienced in mine rescue and recovery work should be in charge of each underground shift as assistant to the man in charge of the entire recovery operations. He should be well versed in mining work and especially in ventilation, mine gases, detective and protective equipment, and procedure following fires or explosions. One or more competent assistants and such other personnel as may be necessary to conduct recovery work safely and efficiently should be assigned to the man in charge of the shift. If exploratory and other work is being done by oxygen breathing-apparatus crews, the man in charge of the shift or one of his assistants should always be at the fresh-air base.

The man in charge of the shift should be provided with an up-to-date mine map on which should be marked, as the work progresses, the areas explored, stoppings erected, ventilation restored, location of bodies, locomotives, cars, pumps, mining machines, falls, and other important data.

Change of underground shifts should be made at the fresh-air base to prevent interruption of the work. The man in charge of the shift being relieved should discuss with the man in charge of the oncoming shift the progress made and plans for future work. After completing his shift and reaching the surface, the man in charge of a shift should report at the general headquarters to the man in charge of operations and convey to the latter the data noted on the mine map used on the shift and any other information of importance.
Well-trained crews, physically sound and fit and experienced in the use and care of oxygen breathing apparatus and gas masks, are an essential part of any organization engaged in rescue and recovery operations. At least some, and preferably all, of the men composing such crews should have had experience in actual recovery work. They should be provided with all the equipment, in excellent condition, necessary to conduct the work successfully. When explorations are being made or other work is carried on with oxygen breathing apparatus ahead of fresh air, at least two complete crews with adequately charged apparatus should be available. No oxygen breathing-apparatus or gas-mask crew should make an exploration or work in advance of fresh air without a reserve crew at the fresh-air base equipped with oxygen breathing apparatus in good condition and adequately charged.

**Brattice crews**

Brattice men, in charge of a foreman, should be provided to erect temporary stoppings and line brattices of canvas or other suitable material where necessary. Temporary stoppings should be reinforced as soon as possible by stoppings of more substantial construction, such as boards covered with canvas or plastered with wood fiber, or tile, brick, or concrete. As the work advances, men should be assigned to patrol and keep tight the temporary stoppings that have been erected.

**Track crews**

Track men, in charge of a foreman, should repair and clean track to facilitate the movement of material to the advance workers and to remove bodies (if any) as they are recovered.

**Material crews**

Material crews, in charge of a foreman, should be provided to handle and transport promptly and efficiently material such as brattice cloth, boards, timbers, nails, food, coffee, water, and other material from the mine portal or shaft bottom to the advance crews.

**Miscellaneous crews and personnel**

Miscellaneous underground crews, as timbermen, laborers to clean up falls, electricians to install and extend telephones, stretcher bearers (if required), and others if necessary should be provided in charge of foremen. Certified fire bosses, haulage men, telephone attendants, and all others necessary should be at hand to perform the work safely, rapidly, and efficiently. All of the foremen in charge of the different crews, as well as the various members of crews and other underground personnel, should be under the direction of the man in charge of the shift and his assistants, who, in turn, should be under the direction of the man in charge of operations. No person other than those directly engaged in the recovery operations should be permitted underground.
SURFACE ORGANIZATION

The surface organization should include the personnel necessary to handle the equipment and materials required in recovery work underground, to provide facilities for housing and feeding the underground and surface organizations, and to perform various other necessary duties.

GENERAL HEADQUARTERS

A room or building near the mine entrance should be designated and used as headquarters for the man in charge of operations and his assistants. It should have tables, chairs, and telephones connected with those being used underground and on the surface around the mine. Telephone attendants should be on duty at all times and two or more men should be available at general headquarters for errand duty and messenger service where the telephone service is not at hand.

An up-to-date mine map should be provided and all important data placed thereon to indicate the progress of recovery operations. The men in charge of different shifts, foremen of crews, etc., should report progress to the general headquarters at the end of each shift so that officials, inspectors, etc., may be informed of what has been accomplished.

LAMP HOUSE AND ATTENDANTS

A suitable building or room should be provided for charging, issuing, receiving, and repairing electric cap lamps and flame safety lamps. Enough lamp-house attendants should be on duty at all times to distribute lamps promptly to men entering the mine, to collect from those leaving the mine, and properly clean, charge, and repair the lamps being used; this lamp service is important and it should be done well.

MESSROOM AND ATTENDANTS

Members of the underground and surface organizations, relatives and friends of persons killed or injured, officials from other companies, and other visitors must be fed. For this purpose there should be a commissary and mess in charge of some designated person, with enough cooks, waiters, dish washers, etc., available. The mess should be housed in a suitable building, room, or tent and be provided with tables, benches, stoves, cooking utensils, dishes, etc., so that the persons assigned to this duty can have a supply of hot, wholesome food available at all times for those engaged in the recovery work. Hot coffee and food, particularly fruit, also should be provided and delivered to those on duty underground, special effort being made to supply such food directly to the advance crews.

SLEEPING QUARTERS AND REST ROOMS

Men engaged in recovery work should have a comfortable place to rest and sleep where they will not be disturbed either by the other workers or in any manner, as the work is strenuous and demands expenditure of both physical and nervous energy. Therefore, if
possible, separate sleeping quarters should be provided for the men of each shift in order that they may obtain the maximum amount of rest while off duty. Sleeping quarters should be in a quiet place, properly heated in cold weather and provided with comfortable cots and sufficient bedding.

A comfortable rest room, separate and some distance from the sleeping quarters and provided with tables, benches, or chairs, lights, etc., should be available for men not sleeping or not on duty.

**APPARATUS ROOM AND ATTENDANTS**

A room should be available in which to store, charge, and repair oxygen breathing apparatus, gas masks, and accessories. There should be on each shift at least two men competent to clean, recharge, test, and repair oxygen breathing apparatus and gas masks worn by the underground crews. To expedite extensive recovery work, it may be advisable to establish an underground base for cleaning, charging, testing, and repairing breathing apparatus and gas masks. The base may be moved from time to time to keep it in proximity to working crews.

**INFORMATION BUREAU**

Relatives and friends of persons injured, killed, or missing in a mine disaster naturally are vitally concerned in the recovery work. The public is also interested in the property damage, loss of life, and progress of recovery operations, particularly the rescuing of live men or recovery of bodies. An information bureau to issue information to friends and relatives of entombed men and to press and public should be established. It should be directed preferably by a local mine or other company official or State inspector, and authentic information should be issued from time to time. Properly handled, an information bureau relieves anxiety and grief of relatives and friends, prevents injurious comment by outsiders, and obviates criticism and misleading statements by the press. All information should be issued by an authorized mine official or a representative of the State department of mines.

**EMERGENCY HOSPITAL**

A fully equipped emergency hospital, with doctors and nurses in attendance, should be established in a suitable building. Men found alive in the mine may be affected by noxious gases, severely burned, or otherwise injured; or some of those engaged in recovery work may require immediate hospital attention for injuries or effects of irrespirable gases.

**MORGUE AND ATTENDANTS**

Provision must be made for receiving the bodies of those killed in a mine disaster and preparing them for burial. If the mine is adjacent to a town or city, it may be convenient or desirable to take the bodies immediately to an undertaking establishment; however, where this is not possible or desirable, an improvised morgue should be established. This building preferably should be located some distance from the
mine, should be well ventilated, and should have good drainage facilities. A reliable man, with the necessary assistants, should be placed in charge of the morgue to make a record to identify as far as possible all bodies delivered to the morgue and to take possession of personal effects found with each body and deliver them to relatives. Undertakers and their assistants should prepare bodies for identification by relatives and friends and later for burial.

**LABORATORY AND ATTENDANTS**

Analyses of mine-air samples are often necessary in planning rescue and recovery operations after a mine fire or an explosion. It may be vitally important to obtain information quickly on the composition of mine air in a section of a mine, a return airway, or from behind fire seals. A room with suitable apparatus and materials should be provided with competent attendants available to analyze promptly and efficiently air samples delivered to the laboratory.

**MISCELLANEOUS CREWS AND PERSONNEL**

Miscellaneous surface crews, responsible to foremen, should be appointed to obtain, handle, and transport material required underground to the mine opening or to the bottom of the shaft, to pass out and check equipment and supplies, and to perform other necessary duties.

The permanent surface organization should take over and supplement, if necessary, the activities and duties performed by the temporary organization. Such organization should include a man to be stationed continuously at the fan; a man or men to search men going underground for smoking material, matches, and lighters, to test all flame safety lamps being taken underground, and to check underground workers into and out of the mine, and prevent unauthorized persons from going into the mine; and guards to see that ropes erected to exclude spectators from proximity to the mine entrance are in place, to keep unauthorized persons outside the ropes, and to see that roads leading to the mine are kept open for transportation of men and material.

All of the officials, foremen in charge of crews, and other surface workers, as well as the underground workers, should be under the direction of the man in charge of operations.

**EQUIPMENT**

The safety and protection of men engaged in rescue and recovery operations demand that an ample supply of the proper type of protective, detective, lighting, and fire-fighting equipment and analytical apparatus in first-class condition be available.

**OXYGEN BREATHING APPARATUS AND GAS MASKS**

Self-contained oxygen breathing apparatus and gas masks will be required by crews working in advance of fresh air, and enough of them in good condition, together with spare parts and supplies, should be available. The safe use of approved gas masks will be
limited to places where a lighted flame safety lamp (or a candle in metal mines) will burn.

**DEVICES FOR DETECTING GASES**

Safety and good mining practice require that ample means be provided for the detection of mine gases by competent persons designated to use them. The necessary devices for detecting mine gases are permissible flame safety lamps, U. C. C., M. S. A., or Burrell methane indicators, possibly continuous methane recorders (main return only), carbon monoxide detectors or canaries or both, and portable gas-analysis outfits. Sufficient supplies and spare parts to insure efficient operation of the gas-detecting devices should be available at all times. These devices should be used only by persons fully acquainted with them and their limitations.

**DEVICES FOR ILLUMINATION**

Men engaged in rescue and recovery operations in coal mines should be provided with permissible electric cap lamps or flashlights, or both, for illumination. In some instances permissible floodlights can be used to advantage and, if required, should be provided.

In metal mines approved illuminating equipment is also preferable, as it will add to the safety and efficiency of the crews. In modern coal mines (and many metal mines) approved electric cap lamps are used exclusively for illumination and therefore will be available for use after a mine fire or explosion. Where permissible electric cap lamps are not regular mine equipment, at least 50, with necessary equipment for charging and repairing, should be provided at the earliest possible moment for use in recovery operations.

**PERMISSIBLE ELECTRIC LAMPS**

Under Schedules 6, 6A, 6B, and 6C, the Bureau of Mines has approved various types of electric cap lamps, hand lamps, flood lamps, trip lamps, and animal lamps as permissible for use in gassy and dusty mines.

**CAP LAMPS**

Various models and designs of the Hirsch, Hubbell, General Electric, Manlite, Wico, Concordia (Ceag), Edison, and Wheat electric cap lamps have been approved. Many of these are no longer manufactured or used and therefore will not be considered. The two types of lamps in general use are the Edison and Wheat, several different models of which are available. Following is a brief description, with illustrations, of the latest models of the Edison and Wheat electric cap lamps:

*Edison (model K) lamp.*—The latest model Edison electric cap lamp (fig. 3) has a three-cell, Edison, nickel-alkali electrolyte battery in a monel-metal case with a magnetic lock. A bakelite headpiece provided with a two-filament (main and emergency) bulb, a reflector,

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lens, switch for operating the lamp, and a device for fastening to a miner's cap is connected to the battery by means of a rubber-covered cable. The headpiece switch is designed so that the current can be switched from either the main or emergency filament or turned on or off of either filament. The headpiece safety device consists of a spring that holds the bulb in the electric circuit as long as the bulb is intact, but provides that it falls out of the circuit if the bulb is broken. The headpiece is also sealed with a lead seal. The Edison model K cap lamp was approved by the Bureau of Mines (approval 25) on August 31, 1931. Three bulbs, designated by the symbols B. M. 25, B. M. 25A, and B. M. 25B on the base of the bulb, are approved for use with this lamp. The complete lamp weighs 5 pounds 6 ounces.

Super-Wheat (model W. T. A.) lamp.—The latest model Wheat electric cap lamp (fig. 4) has a two-cell, lead-acid battery enclosed in a molded rubber case. A molded rubber headpiece equipped with a
two-filament main bulb, a small emergency bulb, a reflector, lens, switch for operating the lamp, and a device for fastening to a miner’s cap is connected to the battery by means of a rubber-covered cable. The headpiece switch is designed so that the current can be switched from either the main or emergency bulb and turned on or off either bulb. The headpiece safety device consists of springs that hold the bulbs in the electric circuit as long as the bulbs are intact, but provides that they fall out of the circuit if broken. The headpiece is also sealed with a lead seal. A unique feature of this lamp is that the battery can be charged through the headpiece without disconnecting it from the battery. The Wheat W. T. A. cap lamp was approved by the Bureau of Mines (approval 20) on November 19, 1934. Three bulbs, designated by the symbols B. M. 20b, B. M. 20c, and B. M. 20d on the base of the bulb, are approved for use with this lamp. The complete lamp weighs 4 pounds 8 ounces.

**FLASH LAMPS**

The demand for approved flashlights for use in rescue and recovery work and by mine officials resulted in the development of such lamps. Under Schedule 11 and 11B, the Bureau of Mines has approved the following lamps:

*Eveready flashlight.*—The first type of this flashlight (fig. 5) consists of three dry-cell batteries, polished reflector, bulb, and lens enclosed in a metal case. The case is provided with a switch for operat-

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ing the lamp, and the light can be focused by adjusting the position of the reflector and the threaded bottom part of the case. There is space, also, for an extra bulb in the bottom part of the case. The safety feature consists of a spring that holds the base of the bulb in contact with the electric circuit; if the bulb is broken the spring ejects the base of the bulb and breaks contact. The lamp was approved by the Bureau of Mines (approval 601) on October 22, 1924.

A later type (fig. 6) of the Eveready flashlight (industrial model) has a bakelite instead of a metal case. It also differs slightly in other respects, particularly in the focusing, which is accomplished by mov-

Megolite flashlight.—This type flashlight (fig. 7) consists of three dry-cell batteries, polished reflector, bulb, and lens enclosed in a coharcite case. It is possible to focus the spotlight by adjusting the
threaded bottom part of the case. An interesting feature of the lamp is that it has no switch; the light is turned on and off by holding the lamp and flicking or jerking the reflector end of the lamp.

The safety feature of the lamp consists of a spring that holds the bulb in contact, but if the bulb breaks the base is thrown away from contact. The lamp was approved by the Bureau of Mines (approval 604) on March 13, 1936.

**Tuffite flashlight.**—This type of flashlight consists of either two or three dry-cell batteries, polished reflector, bulb, and lens enclosed in a tuffite case. The case is gastight, watertight, acid-resisting, and a nonconductor of electricity. The lamp has no switch, the bulb being turned on or off by turning the base of the lamp. It is also focused in the same manner. As a safety feature, the usual spring contact bulb is provided. The lamp was approved by the Bureau of Mines (approval 606) on September 18, 1937.

**MISCELLANEOUS LAMPS**

Various types and models of miscellaneous electric lamps have been developed and approved by the Bureau of Mines under Schedules 10 and 10B. These lamps are designed to meet special requirements or conditions and are as follows: Hand lamps, signal lamps, trip lamps, inspection lamps, animal lamps, and floodlights. Miscellaneous lamps that can be used to advantage in recovery work should be provided as needed.

**FIRE-FIGHTING DEVICES**

Fire-fighting devices and equipment should be available at all mines, as many mine fires reach serious stages only because proper fire-fighting devices, such as fire extinguishers, water, hose, and nozzles, are not available. It is well known that essentially all large fires start as small ones and that usually they can be extinguished easily in the early stages if suitable material or equipment is readily available for prompt use.

**FIRE EXTINGUISHERS**

Fire extinguishers are of two distinct types: Hand extinguishers, which are readily portable and range in capacity from 1 quart to 1 or 2 gallons, and mounted extinguishers fitted with wheels, which are transported on the mine track and have a capacity of about 40 gallons to as much as 100 or more gallons. All types of extinguishers should be tested and inspected regularly and maintained in good operating condition.

**HAND EXTINGUISHERS**

Various models of small portable fire extinguishers can be obtained. The following types are commonly used in or around mines.

**Carbon tetrachloride.**—This type extinguisher consists of a seamless shell, a double-acting pump either enclosed in the shell or attached to the side of the shell, a handle connected to the pump, a filler cap,
and a discharge nozzle. The chemical charge consists of carbon tetrachloride (CCl₄). To charge the extinguisher, it is filled with carbon tetrachloride free of moisture and impurities and treated so it will not freeze until about 50° F. below zero is reached. Carbon tetrachloride is an extremely volatile liquid that, in contact with heat, develops a heavy incombustible vapor. The extinguisher is operated by unlocking the pump handle, pointing the nozzle in the direction of the fire, and operating the pump. The pumping action develops enough pressure to throw the liquid a considerable distance. This type extinguisher is especially desirable for fires of electrical equipment, as the liquid is a nonconductor of electricity. Carbon tetrachloride extinguishers should not be used without respiratory protection in confined places or where ventilation is poor, as the vapors and fumes formed by the liquid in contact with burning material are extremely dangerous.

**Soda acid.**—This type of extinguisher consists of a tank, a wheel cap, a discharge hose and nozzle, an 8-ounce acid bottle, an acid-bottle cage attached to the wheel cap, and a loose-fitting lead stopper that rests in the neck of the acid bottle.

The chemical charge consists of 4 ounces of concentrated sulphuric acid and 1½ pounds of bicarbonate of soda. To charge the extinguisher, the outer tank is filled with bicarbonate of soda dissolved in water; the acid bottle, with the lead stopper inserted, is then placed in its supporting cage, the cage and wheel cap are placed in the tank, and the wheel cap is screwed tightly in place.

To operate the extinguisher the operator inverts it, permitting the loose lead stopper to fall free and the acid and soda solution to mix, and at the same time points the hose and nozzle toward the fire. The chemical reaction in the extinguisher develops a pressure of about 100 pounds, which forces the liquid out of the nozzle. The range of the stream is about 30 feet, which makes it possible for the operator to attack the fire from a safe distance.

**Foam.**—This type of extinguisher consists of an outer tank, a wheel cap, a discharge hose and nozzle, an inner cylinder extending the length of the tank, and a loose-fitting stopper that serves as a cover for the inner cylinder. The chemical charge consists of a canister of powdered chemical “A” (aluminum sulphate), a canister of powdered chemical “B” (sodium bicarbonate), and a can of foaming ingredient.

To charge the extinguisher, the chemical “B” is dissolved in lukewarm water and the foaming ingredient added. This mixture is then placed in the outer tank. The chemical “A” is dissolved in hot water and placed in the inner cylinder. The inner receptacle is then inserted in the outer tank, the stopper slipped in place, and the wheel cap screwed tightly in place.

To operate the extinguisher the operator inverts it, thus permitting the stopper of the inner cylinder to fall free and the “A” and “B” solutions to mix, and at the same time points the hose and nozzle toward the fire. The chemical reaction develops about 40 pounds pressure and generates a tough, durable foam which is expelled from the nozzle. The range of the stream is about 30 feet, making it possible for the operator to fight some types of fire from a safe distance.
Carbon dioxide.—This type of extinguisher is a late development in equipment of this kind. It consists of a heavy-duty steel cylinder that serves as a container for the carbon dioxide liquid, a screw-type discharge valve that seals the liquid in the cylinder, an operating handwheel, a locking pin that holds the handwheel disengaged from the valve proper, a safety disk designed to rupture at 2,800 to 2,900 pounds, a flexible reinforced hose, an insulated hose grip, a discharge tube, and a carrying handle.

The extinguishers are received from the manufacturer already charged. The carbon dioxide in the cylinder, due to pressure when charging, takes the form of a liquid, changing to a gas or a solid (carbon dioxide snow) as soon as the discharge valve is opened.

To operate the extinguisher it is either held or set firmly on the ground. The operator then withdraws the locking pin from the hand wheel, thus permitting the hand wheel to snap downward and engage the stem of the discharge valve. The discharge tube is then released and the hose grip held firmly in one hand while the discharge valve is opened with the other hand, releasing a cloud of gas and carbon dioxide snow.

The discharge range of this type of extinguisher is limited to about 5 or 6 feet; consequently, the operator must approach as closely as possible to the fire.

Mounted Extinguishers

Large fire extinguishers (commonly called fire trucks) are used by some mining companies. These extinguishers are mounted on mine-car trucks equipped with flanged wheels and designed to be hauled on the mine track by a mine locomotive. Because of their large capacity, extinguishers of this type, if quickly available, are preferable to the hand type for fighting fires of serious proportions.

The extinguishers are stored either on the surface or underground, depending on storage facilities and whether they are to be available for surface as well as underground use.

Large mounted extinguishers generally are of the soda-acid or foam type. However, some of them are designed to use water instead of chemicals.

Chemical.—One type of mounted extinguisher (fig. 8) consists of two soda-acid tanks having a capacity of 100 gallons each. The truck is equipped also with 200 feet of chemical hose having a nozzle with a shut-off valve, two 1-quart, carbon tetrachloride, hand extinguishers (or two 2½-gallon soda-acid or foam extinguishers), five all-service gas masks, one carbon monoxide detector, two gages for indicating pressure in the tanks, one floodlight, extra chemical charges, tools, etc. This extinguisher and equipment can be obtained also in the two 40-gallon-size tanks designed to use foamite instead of soda acid.

Water.—At least one mining company has designed and is using a mounted fire truck equipped to use water. This extinguisher (fig. 9) consists of a tank having a capacity of about 325 gallons of water. A pump and pipe connection to apply pressure to the water being used from the tank furnishes a stream of considerable pressure. The pump and connections can be used also to pick up water from either a water hole or a pipe and force it into the tank. The tank also can be filled through a small opening in the top.
The truck is equipped with 250 feet of 1½-inch linen-covered fire hose with nozzle, five all-service gas masks, two 2½-gallon chemical fire extinguishers, a roll of brattice cloth, a crosscut saw, picks, shovels, slate bars, and other equipment and tools.

A reel containing a cable and mounted on one side of the tank can be used to obtain electric current for operating the pump in advance of trolley-wire installation.

Other types of mine fire trucks used by some companies are equipped with a number of various types of fire extinguishers, tools, gas masks, and materials for fire-fighting work. One company maintains a fire trip composed of several mine cars equipped with a pump, brattice cloth, tools, gas masks, etc. This trip is stored at a convenient point underground and kept ready for emergency use.

An adequate supply of standard-size fire hose in good condition and with proper fittings, including several nozzles, should be available at all mines for fire fighting. Special types of nozzles, such as perforated pieces of pipe closed on one end and threaded to fit a hose connection on the other end, are often of decided value in fighting underground fires. Various sizes of connections, reducers, and adapters should be available to connect fire hose readily to all sizes and openings of pipe lines.

Rock dust can be used efficiently in extinguishing mine fires when it is possible to apply the dust directly on the fire, and numerous instances are on record of the successful use of rock dust in combating mine fires. A sufficient supply of rock dust in suitable bags should be kept available at all times for fire fighting and general use.
TOOLS

An adequate supply of hammers, axes, saws (hand and crosscut), sledges, hatchets, picks, shovels, bars, bricklayers' hammers and trowels, pipe wrenches, and other necessary tools should be available. To minimize the likelihood of ignition of gas through sparks it is desirable, if not imperative, that hammers, bars, etc., of copper or other relatively nonsparking material be provided for work being done in the presence of explosive gas.

TELEPHONES

Enough telephones always should be available at the base of operations and at such other places as may be necessary to keep contact between those engaged in the recovery work underground and those assisting in various capacities on the surface. After an explosion, as recovery work progresses, the telephone system should be kept in proximity to the fresh-air base at all times.

Under certain conditions the common types of outside and mine telephones can ignite an explosive mixture of gas. Therefore, permissible-type telephones should be used in mines, especially during rescue and recovery operations.

The Bureau of Mines, under schedule 9A, approved a mine telephone manufactured by the Western Electric Co. (approval 901) on July 16, 1927.

Portable telephones that operate without batteries have been developed so that they can be used efficiently and satisfactorily for communication between oxygen breathing-apparatus or gas-mask crews and the fresh-air base.

The equipment (fig. 10) consists of a receiver attached to a head set and throat transmitter and provided with a strap and worn by the crew captain, being attached by a jack or plug to one end of about 1,000 feet of light insulated cable. The cable is wound on a light metal reel, which is suspended and encased in a wooden frame. The other end of the cable passes through the core of the reel and is attached to two insulated commutators fastened on the outside of one of the reel flanges. Two bronze springs are in contact with the commutators and connect, by an insulated wire, with a telephone jack attached on the inner side of the frame.

A combination hand set, containing a transmitter and receiver, for use of the man at the fresh-air base is connected (“plugged in”) to the jack on the frame. A detachable crank for turning the reel and a short chain with a snap for attaching the cable to a convenient place on the oxygen breathing apparatus or gas mask worn by the crew captain complete the equipment. The transmitters of the telephones are voice-energized and no electric current is used, which makes this type of telephone equipment especially desirable for rescue and recovery work. It is possible with this equipment to conduct an ordinary conversation satisfactorily through 2,500 feet of cable.

The captain of the crew attaches the cable to his apparatus by the chain and snap, places the head attachment over his head with the

receiver over one ear, and straps the transmitter loosely around his neck; while talking he holds the transmitter against his throat. As the mouthpiece of an oxygen breathing apparatus offers considerable hindrance to talking, the crew captain should reduce his conversation to a minimum.

A telephone system of this kind should be provided, as it will greatly facilitate the work of oxygen breathing-apparatus and gas-mask crews where a life line is required and enable the man in charge of the fresh-air base to keep in communication with the crews working ahead of fresh air much more efficiently than if a life line were used.

Mine maps, with the latest possible extensions of surveys, should be provided as soon as possible after a mine fire or explosion. One of these should be posted in the general headquarters on the surface and additional copies should be available for the men in charge of the underground shifts, captains of oxygen breathing-apparatus crews, State mine inspectors, and others who may require a copy.

Some mining companies maintain a disaster map for emergency use, on which is noted the direction of ventilation in each entry, location of overcasts, doors, pumps, elevations, and other information. A map of this kind may be of much value after a fire or explosion.
LOCOMOTIVES, ANIMALS, AND CARS

To expedite the movement of material, bodies, etc., after a mine disaster, means of transportation should be provided.

After a mine fire, it may be impossible or inadvisable to have electric current in at least one section of a mine and probably the entire mine, and after an explosion all electric power should be cut off the mine; it will be unsafe to use trolley-pole or cable-reel locomotives.

That there may be motive power for haulage purposes, permissible storage-battery locomotives or animals, such as mules or horses, should be provided. Enough mine cars in good condition should be available for transporting equipment, materials, bodies, etc.

ANALYTICAL APPARATUS

Analyses of mine-air samples may be highly important, and proper facilities should be provided for making them. For the quick determination of carbon dioxide, oxygen, carbon monoxide, methane, nitrogen, and probably hydrogen, a Bureau of Mines type, portable, water Orsat apparatus with the necessary chemical solutions and electrical connections should be available.

Although the portable Orsat apparatus is not highly accurate, it is possible to determine, with careful operation, the percentage of the various gases to within about 0.20 to 0.30 percent. When greater accuracy is necessary, laboratory-type equipment should be provided or the samples taken to a laboratory having apparatus of greater accuracy.

PUMPS

Mine pumps of various designs and sizes should be available. Main pumps should be put in operation as soon as possible to prevent flooding of the mine or sections of a mine. Field or gathering pumps also should be provided to remove water collected in places that would interfere with recovery work and to supply water for fire fighting and other purposes.

CLOTHING

Rescue and recovery crews and other underground workers should wear safety clothing such as protective caps, shoes, goggles, gloves, etc. Members of underground crews should report to the mine equipped with proper clothing; however, it is very important that extra supplies of gloves, socks, boots, shoes, caps, underwear, shirts, overalls, etc., should be available to provide clean, dry clothes for workmen who get wet or damage their clothing.

MISCELLANEOUS EQUIPMENT

Additional miscellaneous equipment and devices that may be required and should be provided as needed are anemometers, barometers, maximum and minimum thermometers, water gages, air-sampling tubes, oxygen inhalers, self-rescuers, stretchers, blankets, first-aid supplies, life lines for apparatus crews, mortar boxes, buckets, etc.
MATERIALS

The materials required for conducting recovery operations to a considerable extent will depend upon local conditions and the nature of the work. Every expedient should be utilized in procuring and making available, when and where needed, the materials required to conduct recovery work efficiently. Lack of necessary materials will retard recovery operations unduly and also will add to the hazard of those engaged in the work. The following materials should be provided as needed:

**BRATTICE CLOTH**

Brattice cloth will be required for temporary stoppings when a mine fire must be sealed. If the area or mine involved in an explosion is extensive, a large amount of brattice cloth will be required for temporary stoppings, line curtains, and other purposes. Several kinds of brattice cloth, ranging from jute, the most commonly used, to heavy canvas, are obtainable. Some types have been treated to make them more or less fire-resistant. An ample supply of this important material should be available at all times.

**LUMBER**

An adequate supply of boards of various sizes, planks, two-by-fours, etc., should be provided as required for constructing semipermanent stoppings and doors, for repairing or rebuilding overcasts and air locks, and for other uses.

**NAILS AND SPIKES**

An ample supply of nails and spikes of various sizes should be available. If numerous stoppings are to be erected and other construction work is necessary, a large supply of nails will be necessary. Copper nails should be provided if work in explosive gas is required.

**BRICK, CONCRETE BLOCKS, AND TILE**

Bricks, concrete blocks, and tile, where readily available, are very useful for building permanent stoppings and overcasts following an explosion and for erecting fire seals when a fire must be sealed.

**PORTLAND CEMENT**

Sufficient portland cement should be available for mortar when brick, concrete-bloc, and tile stoppings or other masonry work are to be erected and for more extensive use if concrete stoppings or other concrete work is necessary.

**WOOD FIBER**

Wood fiber in suitable bags should be provided for plastering to make wood stoppings, doors, etc., as airtight as possible. An efficient stopping can be erected with rough boards if the cracks and crevices are plastered with wood fiber. The wood fiber should be mixed with water to the consistency of heavy mud and then applied with a trowel or the hands. Wood-fiber plaster sets quickly; therefore, it is best to mix it at the place of use; and if acid mine water is used, it sets even more quickly.
PROCEDURE IN SEALING AND UNSEALING MINE FIRES

POSTS AND TIMBERS

A generous supply of mine posts, cap pieces, wedges, and heavy timber should be provided for roof support and for erecting canvas or board stoppings.

PIPE AND PIPE FITTINGS

Pipe of various sizes, with an ample supply of sleeves, elbows, tees, unions, reducers, valves, etc., should be provided for extending water lines, for suction and discharge lines for pumps, and for other purposes as may be required.

WIRE, INSULATORS, HANGERS, ETC.

Proper types and sizes of wire, hangers, roof bolts, insulators, etc., for telephone, signal, and power-transmission lines and for such other purposes as may be necessary should be provided as needed.

MISCELLANEOUS MATERIALS

In addition to the above, other miscellaneous materials, such as rock dust, ties, rails, frogs, switch points, track spikes, etc., and repair parts for equipment, devices, and machinery should be provided as required.

PROCEDURE FOLLOWING MINE FIRES

Proper procedure in fighting, sealing, and unsealing mine fires is of the utmost importance. Wrong procedure may result in one or more of the following:

1. Men working in the mine when a fire occurs may be needlessly exposed to or overcome by smoke and fumes from the fire.
2. An explosion with possible loss of life and property may occur during the fighting, sealing, or unsealing operations.
3. The lives of those engaged in fighting, sealing, or unsealing a mine fire may be jeopardized or sacrificed needlessly.
4. Property loss may be increased or curtailment of production prolonged.

The destruction of life and property and the demoralization and disorganization that frequently accompany mine fires cause them to be anticipated with dread by mining organizations. Mine fires are far more dangerous to handle than are explosions, unless the explosion has left in its wake one or more fires; with an explosion usually the worst is over, but with a mine fire the worst is yet to be feared. A tremendous toll in lives has been taken by asphyxiation or by explosions resulting from fires in mines, and unestimable property damage has resulted from them. As procedure in fighting, sealing, and unsealing mine fires differs considerably from that followed after explosions, it is discussed under a separate heading.

No fixed rule can be laid down for the control and extinguishing of mine fires, for each fire presents a more or less original problem, depending on the conditions encountered. However, it can be stated definitely that in any mine a fire is serious and dangerous, even if the mine or section of the mine in which the fire is liberates little or no explosive gas; under mine-fire conditions normally nongassy mines or sections of mines may become dangerously gassy through
distillations from the fire. Due consideration should be given to the safest means of extinguishing any mine fire, regardless of the property damage or loss of equipment that may result. Frequently, efforts are made at considerable risk to fight fires directly, to prevent interference with production or to save equipment, when they could be sealed with little or no risk.

Although the information in this circular relating to the fighting, sealing, and unsealing of mine fires refers primarily to coal mines, most of it is applicable also to metal mines, with the possible exception of that on explosive gases; however, explosive gases are found sometimes in connection with metal-mine fires.

**METHODS OF CONTROL AND EXTINGUISHMENT OF MINE FIRES**

Methods of controlling and extinguishing mine fires are: (1) Fighting by direct attack, (2) sealing the fire area to exclude oxygen, (3) flooding the fire area or the entire mine, (4) flushing with silt or other solids, (5) use of incombustible barriers to prevent the spread of fire, (6) using an inert gas, as carbon dioxide, and (7) unsealing the fire area to recover bodies, to load out smoldering material, or to re-ventilate it.

**FIGHTING MINE FIRES BY DIRECT ATTACK**

Many mine fires are extinguishable in the incipient stage by direct attack with water, chemicals, rock dust, or sand. Failure to extinguish fires by direct attack usually is due to late discovery, lack of water or means for applying it promptly, lack of fire extinguishers or other facilities, and improper procedure in the initial or subsequent attack.

In many instances prolonged efforts extending over several days, even weeks, are made to extinguish a fire by direct attack. Such procedure is usually accompanied by considerable risk to life and property and frequently is unsuccessful. Unless a fire can be extinguished within a few hours by direct attack it is likely to be advisable to resort to some other method.

When mine fires are fought directly, the amount of air reaching the fire should be reduced to a minimum to prevent unnecessary intensification of the fire; only enough air should be used to prevent smoke and fumes from backing up against the air current and to keep the intake side of the fire reasonably clear of smoke. Failure to extinguish a mine fire by direct attack will necessitate an attempt at control or extinguishment by some other method such as sealing, flooding, flushing, etc. Although sealing is the most practical method, where direct attack fails or cannot be used, in some cases conditions are such that sealing cannot be done effectively, and other methods

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such as flooding or flushing, may be preferable or even necessary. In some extreme cases sealing must be followed by flooding or flushing and that by the direct method of loading out the flushed material together with the heated strata, and in some cases this material is handled by steam or electric-shovel methods.

**USE OF WATER**

If sufficient quantity and means of application are available, water is an excellent medium for the extinguishment of mine fires, especially in the early stages. As the fire increases, the water must be applied by hose and nozzles. Falls of roof and coal invariably will occur as the fire progresses and make it difficult to apply water in the most effective manner. A perforated pipe or nozzle connected to a hose having a good head of water and controlled by a valve may be pushed gradually ahead into the active fire, and points beyond the range of ordinary nozzles may be reached; by using this method there is less hazard to persons from falling rock, a large amount of water may be applied quickly and as quickly turned off, and less steam is likely to be formed.

Large quantities of water thrown directly on a fire of considerable extent and intensity, or water thrown on a mass of heated material, will form considerable steam and probably hydrogen. In the absence of adequate ventilation, or as the result of a fall of roof, the steam may be forced on men or the hydrogen may explode with serious or fatal results.

Another method of more or less direct attack by water is to apply it to cool but not extinguish burning material, which is then loaded out by hand or, more satisfactorily and speedily, by a loading machine. Water is used also to wet the heated material thoroughly after it is loaded in cars to prevent the material from flaming during transportation.

**USE OF CHEMICALS**

Direct attack may be made on mine fires in the early stages by chemicals used in the various types of hand fire extinguishers. Larger fires may be fought successfully by large mounted chemical extinguishers. Care should be exercised in using chemicals extinguishers in confined places where there is little or no air movement, as some types of extinguisher (carbon tetrachloride) form dangerous fumes when thrown on a fire and others (soda-acid, foam, and carbon dioxide) form a heavy blanket of irrespirable gas.

**USE OF ROCK DUST**

Fine limestone or shale dust for rock-dusting bituminous coal mines can be used successfully in fighting incipient fires as well as larger fires under some conditions. In the early stages of a fire the dust is applied by hand or with shovels. As the fire progresses, the actively burning material often is partly covered by falls and the rock dust may be poured on top of the fire and falls of smoldering material. Rock dust not only serves to extinguish flame directly but excludes air from burning material, thereby smothering the fire. Rock dust can be used also to cool heated material so that it can be
PROCEDURE FOLLOWING MINE FIRES

loaded more easily and to cover heated material loaded in cars and is preferable to water for such uses, as no steam is formed.

Some mining companies keep rock dust available for fire-fighting purposes at various places throughout the mine.

USE OF SAND

Fine sand, if available, can be used in making a direct attack in essentially the same manner as rock dust; it is heavier, however, and therefore harder to handle, and is usually loose, whereas rock dust generally is placed in sacks of convenient size for carrying and handling.

SEALING MINE FIRES

Mine fires should be sealed when progress cannot be made by fighting them directly or when other conditions, such as inaccessibility and probable dangerous accumulations of explosive gas, make sealing advisable. Temporary seals usually are erected in an effort to exclude quickly most of the air from a fire and later are supplemented by airtight permanent seals.

Considerable difference of opinion exists as to which side (intake or return) of a fire should be sealed first. Many mining men, including the authors, prefer to seal the intake and return airways simultaneously, especially if the fire is in a section of a mine where explosive gas is being liberated. If this is not feasible, because of the distance between openings, or for other reasons, it is advisable to seal the intake airways first. The reasons for sealing the intake-air side first are:

1. Unless it is being fanned vigorously by the ventilating current (which should not be done), the fire will travel mostly toward the fresh-air or intake side. In some kinds of coal, the fire will travel toward fresh air quite rapidly (almost as fast as a man can walk); if the return side is sealed first the fire will burn longer, cover a larger area, and be checked little or none until the intake side is sealed.

2. Ventilation around and over a fire consists of air from the intake side, which, after being heated by contact with the fire, rises to the roof and leaves the fire by the return side; if little or no air is traveling in the ventilating current, the heat of the fire will create ventilation and establish an intake and return air current.

3. As air comes in contact with the fire, much of the oxygen is consumed, and the return side, therefore, generally is low in oxygen, and the quickest way to diminish the oxygen, decrease the flame, and prevent the fire from spreading is to seal the intake airways. When the intake airways are closed, most of the air that the fire can obtain will be from the return side or air that already has passed over the fire and undoubtedly is low in oxygen and consequently will assist greatly in extinguishing flame and preventing an explosion.

4. The authors have assisted with the sealing of numerous fires in gassy sections of mines (some of them extremely gassy) and, unless airways were sealed simultaneously, always have sealed the intake airways first. Furthermore, Bureau of Mines engineers and safety instructors have assisted in sealing hundreds of mine fires (many of these in gassy mines), and, so far as known, at none of these have the return airways been sealed first. In all of this work no serious
explosions occurred during the placing of temporary seals. In some instances explosions occurred some time after the seals were erected, but it is probable that they would have occurred, possibly with greater frequency, if the return airways had been sealed first.

The distance from the fire at which seals should be built will be governed by the nature of the roof and floor, the number of openings to be sealed, the condition of the air in the section involved, and whether the section to be sealed is gassy or nongassy. In metal mines, or in coal mines where no gas is being liberated, the seals preferably should be placed as close to the fire as possible. By sealing close to the fire less area is involved, the oxygen diminishes more rapidly, and the extinguishment of the fire is hastened. Placing stoppings to seal a fire in a gassy section of a mine is dangerous and should be done with the utmost care and consideration; the seals should be placed as far from the fire as possible (1,000 feet or more) to allow considerable time to elapse before an explosive mixture of gas is likely to be formed. A prominent engineer has described sealing a fire in a gassy section of a mine as a race to have the fire deplete the available oxygen before combustible gases can accumulate to the explosive point. An explosion invariably will occur if gas is given off in sufficient quantities to be within the explosive range of methane (5 to 15 percent) before the oxygen has been reduced below the percentage at which an explosion is possible (approximately 12 percent). Under these conditions, it is advisable to erect tight temporary seals and then withdraw all men from the mine for at least 24 hours before attempting to erect permanent seals. Furthermore, if an explosion is likely to occur after the temporary seals are erected, arrangements should be made to close the last seals after all men are out of the mine. This can be done by leaving hinged openings (doors), that will close automatically, in one or more of the stoppings and holding them open with a counterbalance in the form of a perforated bucket filled with water; the perforations should be made so that sufficient time will elapse before the water drains from the bucket to allow the men in the mine to reach the surface before the door or doors close to complete the temporary seals.

As a precautionary measure, it is advisable that a thick coating of rock dust be applied to ribs, roof, and floor of entries, crosscuts, etc., for several hundred feet outby and, if possible, inby the location of temporary seals when fires are being sealed in gassy or dusty mines; hence, in the event of an explosion around the fire there will be little likelihood of propagating a coal-dust explosion. Although it may be possible to seal a fire in a gassy section of a mine without a subsequent explosion during or shortly after sealing operations, undoubtedly the safest method is to seal the mine openings at the surface.

TEMPORARY STOPPINGS OR SEALS

The element of time frequently enters into the construction of temporary stoppings or seals after a mine fire; the quicker they can be erected, the sooner air will be cut off the fire and the flame extinguished. Therefore, readily available materials that require minimum time for construction should be used, provided, of course, they are suitable to give the results desired from the sealing.
Temporary stoppings or seals generally are constructed of brattice cloth or canvas, if available, because they can be erected quickly and can be made fairly tight. If a more substantial stopping is desired, boards covered with brattice cloth or boards with pieces of brattice cloth, stiff mud, or wood fiber packed around the edges and in cracks and holes can be used. Except where stronger stoppings are necessary, wood is generally not as desirable as brattice cloth for temporary stoppings or seals. More time is required for construction, and unless the entire surface of a wood stopping is plastered it is little, if any, tighter than a well-constructed brattice-cloth stopping. Temporary stoppings should be set from 4 to 6 feet or more inside of openings to be sealed to allow room enough to erect permanent stoppings outby the temporary stoppings.

**Brattice cloth.—**If it is necessary to erect a temporary stopping quickly, or if it is not essential that the stopping be especially tight, a brattice-cloth stopping can be erected as follows: Select a suitable point and set a post near each rib, wedging it securely in place. Nail a board (6 to 12 inches wide and about 1 inch thick), extending from rib to rib, across the top and bottom of the posts. Cut a piece of brattice cloth large enough to cover the opening to be closed and hold it in place. Nail the brattice cloth to the top and bottom boards and, if possible, to the ribs. Complete the stopping by shoveling fine material along the bottom. Although a stopping of this type will allow a certain amount of air leakage, it is tight enough for most purposes and can be erected in minimum time. Where time is not a serious factor and a fairly tight stopping is required, or where the stopping must withstand considerable air pressure, a more substantial one of brattice cloth should be erected (fig. 11) as follows: Select a point where the roof and ribs are solid and

![Brattice-cloth stopping.](image-url)
well squared and pick down all loose material. Set posts about 1 foot from each rib and one or more posts (depending on the size of the opening) between the two rib posts. Be sure that the posts are set firmly and that where the floor is soft a mud cap or partial still is set under each post. Nail suitable boards across the top, center, and bottom of the posts. The boards should extend from rib to rib and the top and bottom boards should be placed as near as possible to the roof and floor. If the ribs are irregular, short boards extending from the top to the center and from the center to the bottom boards, following roughly the curvature of the ribs, should be nailed along both sides of the stopping. A piece of brattice cloth or canvas large enough to cover the opening to be sealed, allowing a small surplus on sides, top, and bottom, should be nailed to the boards. Additional layers or plies of brattice cloth, depending on the size of the opening, the air pressure against the stopping, and the thickness and type of brattice cloth, should be nailed on top of the first layer to obtain a tight fit. To close small openings around the edges of the stopping, wooden cleats (small pieces of boards) should be used to push the brattice cloth into all irregularities of the roof, ribs, and floor and should be nailed into place. To obtain maximum tightness it may be necessary to calk the edges of the stopping with pieces of brattice cloth or stiff mud or wood-fiber plaster and to shovel fine dirt against and along the bottom. With reasonable care, a brattice-cloth stopping can be constructed that will allow only slight leakage of air.

Wood.—If brattice cloth is not available for temporary stoppings, or a more substantial stopping is required, various kinds of boards can be used. Usually, rough boards of various widths and about 1 inch thick are used, but for a tight stopping it is advisable to use tongue-and-groove boards. A wooden stopping is erected as follows: Select a suitable place and set, firmly enough, posts in the opening to be sealed. A shallow hitch should be dug in the roof, ribs, and floor, and the boards fitted snugly into the hitch as the stopping is erected. If tongue-and-groove boards are not used and sufficient brattice cloth is available, the entire surface of the stopping should be covered with a layer of the cloth. If brattice cloth is not available, cracks or holes and places where boards are joined should be closed with stiff mud or wood-fiber plaster. In either case, the edges of the stopping should be calked with small pieces of brattice cloth, mud, or plaster. If carefully erected, a wooden stopping of this type will be fairly strong and will allow a minimum of air leakage.

permanent stoppings or seals

The character of the permanent stoppings or seals for sealing a mine fire depends on the materials available, the length of time they are to be in use, the necessity for complete airtightness, and the strength required to withstand pressure or crushing. Permanent stoppings or seals may be built of brick, cement blocks, concrete, tile, wood plastered with wood fiber, mud and cement, or cement mortar, wood with a layer or two of brattice cloth or tarred felt between layers of planks, or pack walls of various kinds. Permanent stoppings erected for fire seals should be well hitched in the ribs, roof, and floor and built snugly into the hitches to make
them as tight as possible. Provision should be made for collecting air samples, taking water-gage readings, and "bleeding off" excess pressure of fire gases by placing a pipe or pipes with suitable valves in one or more of the stoppings. It may be advisable, also, to pro-
vide pipes and valves in some of the stoppings for the purpose of flooding or draining the fire area.

A pipe for collecting air samples may be placed anywhere in a stopping; as, after the gases are diffused, the same mixture is likely to
PROCEDURE IN SEALING AND UNSEALING MINE FIRES

be found anywhere behind the seals. For convenience, usually the pipe is placed near the center of the stopping. The number of stoppings in which pipes should be placed for collecting air samples, etc., will depend upon the area under seal, the number of stoppings used to seal the fire, and their position.

Permanent stoppings should be patrolled regularly, inspected frequently for leaks, and all leaks closed promptly.

Brick.—Stoppings or seals constructed of brick (fig. 12) usually are satisfactory; brick withstands crushing about as well as any material, and the size is well adapted to fitting into the irregularities of the ribs and roof. Brick stoppings should be 9 to 15 inches thick, according to the strength required. A strong cement mortar should be used. One part cement to two parts sand will give great strength and a 1-to-3 mixture will give a strong mortar for general use. The addition of 5 to 10 percent of hydrated lime will make the mortar easier to work and probably quicker to set. After a brick stopping has been completed, the entire face of the stopping and the roof, ribs, and floor for a distance of several feet should be well plastered with cement mortar to prevent air leakage. The National Mine Rescue Association's type of stopping is a modification of a brick stopping for fire seals (fig. 13). The important feature of this stopping is the tile section substituted for some of the bricks. This section is usually placed near the center of the stopping; it is 3 by 3 feet (or larger if desired) and made of 5- by 8- by 12-inch back-up tile. The entire stopping should be well plastered with cement mortar. As it is difficult to make an opening in a solid brick wall, the tile center should be used in all stoppings that must be removed after extinguishment of the fire through which inspection or exploration of the fire area may be made. The tile center can be knocked out easily and, if necessary, the hole may be closed quickly with other tile.

The National Mine Rescue Association, formerly "Smoke Eaters" Association, is composed of men who actually have worn respiratory equipment during rescue and recovery work following mine fires or explosions.
PROCEDURE IN SEALING AND UNSEALING MINE FIRES

Cement blocks.—Cement blocks laid with strong cement mortar may be used to erect permanent seals or stoppings. The blocks are hollow and are not too heavy to be handled conveniently. Sizes are 4 by 5 by 12 inches up to 12 by 12 by 36 inches and probably others. Ease of handling makes these blocks desirable. The tile center described for brick stoppings also can be placed in cement-block stoppings.

Cement-block stoppings should be well hitched into the ribs, roof, and floor to insure tightness; as the blocks may be somewhat porous, the surface of the stopping should be plastered well with cement mortar.

Concrete.—Substantial stoppings may be made of concrete (fig. 14); they are durable, unaffected by water, have a high bearing strength,

and assist in supporting the roof. A form of rough lumber should be erected at the point selected for the stopping and filled with concrete mixture. When the concrete has hardened, the outside form should be removed and all small openings or cracks filled with cement mortar. Concrete stoppings should be at least 6 inches and preferably about 12 inches thick and well hitched into the ribs, roof, and floor. Where the bottom is soft or has a tendency to heave, it may be advisable to lay a foundation course of cement blocks at right angles to the wall to obtain a larger bearing surface.

Tile.—A stopping or seal may be constructed more quickly of tile (fig. 15) than of smaller brick. However, tile will not bear much weight without cracking or crushing and if subjected to pressure or squeezing will not be satisfactory. The strength of tile stoppings can be increased greatly by filling the tile with cement mortar and allowing it to harden before using the tile. Tile stoppings should be well
hitched into the ribs, roof, and floor, and it may be advisable to use bricks to fill in around the edges of stoppings. As tile is somewhat porous, the surface of stoppings should be well plastered with cement mortar.

**Wood and plaster**.—If brick, cement blocks, tile, or material for concrete are not available or an incombustible stopping is not required, permanent stoppings or seals may be erected with boards or plank and plaster. Numerous mine fires have been sealed successfully by wood and plaster stoppings. To erect a board and plaster stopping (fig. 16), firmly set enough posts in the opening to be sealed. To obtain maximum stability, the posts should be set in hitches dug into the roof and floor. Hitches should then be made in the roof, ribs, and floor, boards fitted snugly into the hitches, and nailed to the posts until the stopping is completed. To seal the stopping tightly, cleats should be nailed around the edges and the edges carefully packed with stiff mud, wood-fiber, or mud-and-cement plaster. The entire surface of the stopping also should be covered with a fairly thick coating of plaster. Suitable plaster can be made by mixing wood fiber and water or mud and cement mortar to the proper consistency. Wood fiber and cement mortar are generally available and used. However, where suitable mud is at hand, a mud-and-cement-plaster mixture has advantages as it apparently does not become as hard or crack as readily as wood-fiber plaster or cement mortar. An efficient mud plaster can be obtained by mixing 50 percent mud, such as is found near mine openings that have been flooded or other suitable mud, and 50 percent portland cement. Mud-and-cement plaster of this kind has been used with satisfactory results.

In some instances plaster may not adhere readily to the smooth face of a wooden stopping, and roughening the surface of the boards with a pick point will assist in making the plaster stick. The use

**Figure 16.**—Board stopping plastered with wood fiber.
Of ship-lap boards in constructing the stopping provides a means of holding the plaster in place. The boards are nailed to the posts like clapboards on a house, but upside down. If ship-lap boards are not available, virtually the same effect can be obtained by nailing ordinary boards on the posts so that the upper edge of each board overlaps the bottom edge of the board above. This overlap offers a recess and support that will hold plaster much more effectively than the smooth face of a stopping.

Another efficient method for holding plaster or for placing additional plaster on a stopping is to nail wire netting (chicken wire) over the face of the stopping, about 1 inch from the stopping, and then apply a thick plastic coat of wood-fiber or mud-and-cement plaster.

Another type of wood and plaster stopping may be built of patent laths (fig. 17), which are boards with grooves cut on one surface; the grooves will retain wood-fiber or other plaster effectively. The stopping may be built as follows: Dig a hitch into the ribs, roof, and floor at the point selected for the stopping. Cut a 2- by 4-inch cap, mud sill, and end studs to proper length. Set the bottom of the end studs on the mud sill, place the cap over the studs, and wedge the cap securely in place. Toenail the studs. Place the other studs as shown in the sketch and double studs as indicated. Cut the patent lath to break joints on double studs on each side of the center, nailing the lath on as cut. Cover holes around edges of stopping with short pieces of lath, then apply a heavy coat of wood-fiber or mud-and-cement plaster.

A more substantial type of wooden stopping can be constructed by using two layers of plank with a layer of tarred felt or brattice cloth between (fig. 18). Three or four posts should be set firmly in the opening to be sealed, hitches should be dug into the roof, ribs, and floor, and a layer of plank 2 inches thick and of convenient width (usually 10 inches) should be nailed to the posts. Over this layer of plank a layer of tarred felt or brattice cloth should be nailed, after which another layer of plank should be nailed over the tarred felt or brattice cloth. The stopping should be completed by plastering the edges with mud and cement or wood fiber. The entire face
of the stopping can be plastered also; however, this usually is not necessary if the stopping is constructed properly.

PROCEDURE FOLLOWING MINE FIRES

Figure 18—Sketch of plank and tarred-felt stopping.

An opening may be left in the stopping and a door, slightly larger than the opening, constructed in the same manner as the stopping. The door is placed on the inside of the stopping, hinged at the top
with strap hinges, and fastened shut by bolts to plank crosspieces placed either vertically or horizontally over the door opening. The crosspieces used to hold the door shut should have holes drilled in them on the proper centers to fit over the bolts when the door is closed. The crosspieces should not be nailed but should be left free to shift, so that the holes may fit the bolts. When hinges are not available for attaching the door a strip can be nailed on the stopping below the door opening, on which the edge of the door can be placed to hold it in position while it is being bolted. After the door has been bolted in position the edges of the opening, where they meet the door, should be well plastered.

Pack wall.—A pack-wall stopping may be used for permanent stoppings or seals, especially in the absence of other suitable materials. One type is constructed by setting two rows of posts, about 18 inches apart, in the opening to be sealed. Hitches should be made into the ribs, roof, and floor. Boards should be nailed on the inby row of posts, and as the boards are nailed on the outby row of posts the space between the boards should be filled with clay or loam.

If boards are not available, another type of pack-wall stopping may be constructed of rock with the space between the walls filled with clay or loam. The outside wall should then be plastered to make the stopping as tight as possible. It may be possible, also, to construct a single rock wall, well hitched and plastered, that will be tight enough to seal a fire effectively.

If boards, rock, or other suitable materials are not available, or if a strong stopping is necessary to withstand pressure, another type of pack-wall stopping may be constructed by digging a long hitch into the bottom, ribs, and roof and placing a layer of screened dirt several inches deep in the bottom hitch, on top of which should be laid a row of mine posts of fairly uniform size, parallel with the opening to be sealed. The openings between the mine posts should then be filled with screened dirt or loam, which should be well tamped between the posts, filled to several inches above the posts, and another layer of posts added. The stopping is completed by alternate layers of posts and tamped dirt or loam. Such stoppings have been used successfully in sealing several mine fires. Where the stopping will be subjected to excessive pressure or squeezing, this type often may be preferable to any other, as it becomes tighter and will not crack or break under pressure. Figure 19 shows various types of pack-wall stoppings.

Flooding Mine Fires

Occasionally a mine fire occurs where it may be extinguished easily if sufficient water is available to flood it, the water extinguishing the fire either by direct contact or by forming a seal and excluding air.

In other cases, where explosions have occurred or are occurring frequently, making it extremely hazardous to fight the fire by direct attack or to seal it, the fire area or entire mine may be flooded safely and the fire extinguished. Also, after stoppings have been erected to seal a fire area, flooding is sometimes employed to hasten extinguishment or to assist in excluding air when the stoppings, coal, or strata are not airtight.
Flooding is likely to be an expensive method of extinguishing mine fires, as it usually requires considerable labor and material to introduce the water and to pump it out after the fire has been extinguished. Moreover, the effect of water on mine roof, equipment, etc., doubtless will result in much additional expense.

**FIGURE 19.—Sketch of pack-wall stoppings.**

**FLUSHING MINE FIRES**

Under certain conditions, flushing with silt or other solids is a desirable method of extinguishing a mine fire, especially where the area or the mine probably will not be reopened or where the strata
PROCEDURE IN SEALING AND UNSEALING MINE FIRES

are so broken that neither sealing nor flooding is effective. Generally, stoppings are erected to seal the fire area in so far as sealing can be done, and then the area is flushed by introducing silt or other material. The usual method is to suspend the fine silt in water and flush the mixture of silt and water into the fire area through drill holes or otherwise. After the mixture reaches the fire area and its movement is arrested, the water drains off, allowing the silt to settle and fill most or all of the openings, thereby extinguishing the fire. This method has been used successfully in controlling some metal-mine fires.

USE OF INCOMBUSTIBLE BARRIERS TO PREVENT SPREAD OF FIRE

Incombustible barriers have been used successfully in several abandoned coal mines to prevent the spread of fire. This method of control is adaptable only where the barrier can extend from outcrop to outcrop to isolate the fire. Briefly, the method is as follows: A tunnel or open-cut, or both (about 12 to 20 feet wide), is cut through the coal bed from outcrop to outcrop and a safe distance from the fire. All combustible material is removed and the opening is completely backfilled with incombustible material, usually clay or a mixture of sand and clay, flushed from the surface through drill holes spaced approximately 50 feet apart.

USE OF INERT GAS

Inert gas such as carbon dioxide (CO₂) occasionally may be used to advantage in cooling or extinguishing a mine fire; however, the use of inert gas is an expensive, laborious, and often unsuccessful method. If effective seals are erected and the fire area is airtight, enough inert gases will be produced by the fire and by the consumption of oxygen to extinguish the fire within a short time. If the fire area is not sealed tightly or no seals are erected, it is questionable whether the use of inert gas, such as carbon dioxide, will be effective. Where claims of the effective use of carbon dioxide have been made, it is likely that conditions have been especially favorable, as its use is known to have been unsuccessful in several attempts.

The usual method of using carbon dioxide is to allow it to flow from 100- or 200-cubic-foot cylinders on or over the fire, or to force it through openings of fire-area stoppings. Another method is to bore holes into the fire area and introduce the gas through the holes. Liquid carbon dioxide has been injected, under about 70 pounds pressure, into the fire area through pipes in stoppings. It has also been used by driving perforated pipes into burning or smoldering material and forcing it under pressure through the pipes. Recently it has been suggested that dry ice (solid carbon dioxide) under some conditions might be used effectively in controlling or extinguishing mine fires.

UNSEALING MINE FIRES

The question of when and how to unseal mine fires is of vital importance to the mining industry. If a fire area is unsealed too soon, the hazard to life and property is always increased; this dangerous practice has been followed and seemingly continues to be
used with unusual frequency, with resultant loss of life and other enormous economic losses. The premature opening of sealed mine fires is due most frequently to lack of knowledge of the inherent danger involved and to extreme eagerness to restore the sealed area to a production basis. While material for this paper was being collected, it was discovered that State mining laws and authorities on mining give little information that would adequately assist those confronted with this problem. This lack can be attributed largely to the failure of mining men in the past to consider this problem as seriously as its importance merits. The control of fires by sealing and the time for unsealing are based on established laws of physics and chemistry, as well as experience and sound judgment of surrounding circumstances. Through the aid of chemists versed in the technique and interpretation of fire gases in sealed areas, a reasonably accurate knowledge of the composition of fire gases is available, and hence there is opportunity to determine the potential hazard involved and when the seals can be broken with the least hazard.

Next in importance to determining the right time for unsealing is an efficient organization and ample provision for necessary equipment and materials to be used by those who are to undertake this hazardous task.

**FACTORS GOVERNING TIME FOR UNSEALING**

Unsealing any mine fire is hazardous and should not be treated lightly by those engaged in the work. Although a sealed area containing explosive gas undoubtedly presents the most dangerous condition, all mine fires should be considered as potential hazards when the time for unsealing them arrives. Besides making sure of the proper time for unsealing the fire area those engaged in the work should be safeguarded in every possible way.

Experience and scientific study have shown that no attempt should be made to unseal a mine fire (1) until the oxygen content of the sealed atmosphere is low enough to make explosions impossible, irrespective of the amount of combustible gases or dusts that may be present, and (2) until the carbon monoxide (CO), the indicator of combustion, has disappeared. In addition, the sealed area should be given time to cool to minimize the chance of rekindling when air is admitted. In substance, some of the principal factors that govern the time for unsealing fire areas, as gained from personal experience, observation, and consultation with experienced mining men are: (1) Extent and intensity of fire at time of sealing; (2) character of burning material and overlying strata; (3) tightness of seals and enclosed area; (4) influence of barometric pressure on the enclosed area; (5) position of the fire area with respect to ventilation; (6) sampling and analysis of the atmosphere under seal; and (7) composition of fire gases in the sealed area.

**EXTENT AND INTENSITY OF FIRE AT TIME OF SEALING**

The extent and intensity of the fire at the time of sealing will have a decided bearing upon the reduction of oxygen in the sealed area. For instance, a large amount of burning or heated material will hasten the reduction of oxygen but will lengthen the time required
PROCEDURE IN SEALING AND UNSEALING MINE FIRES

to cool; also, a fire that is active at the time of sealing will cause oxygen to diminish more rapidly than will a smoldering fire.

CHARACTERISTICS OF BURNING MATERIAL AND OVERLYING STRATA

The character of the burning material (that is, whether it is wood, bituminous coal, or anthracite), the rate of burning, and the change of gas composition are factors that may influence rekindling when air is again admitted. Coals that are high in volatile-combustible matter burn faster and are more likely to rekindle when air is admitted than are coals or material low in volatile-combustible matter. The character of the strata overlying the coal bed plays an important part in determining the time for unsealing. For example, an oily shale roof that presumably has covered a fire will retain heat for a long time, even after the oxygen content of the sealed area is reduced to a point where combustion is impossible. There have been instances where such a roof was hot 30 days after the oxygen content of the fire area had been reduced to below 3 percent. Under such conditions, the chance that the fire will be rekindled when air is admitted is increased considerably; furthermore, it is extremely difficult to get to the seat of the fire for a long time where the combustible roof has caved and covered the fire. Another striking example of caved combustible roof materials aggravating the fire under seal is where there is a coal roof or where the roof immediately over the coal is composed of alternate bands of bone, shale, and coal, some of which is fairly high in sulphur. Combustible floor material also retains heat and tends to lengthen the period that should elapse before an attempt is made to unseal.

TIGHTNESS OF SEALS AND ENCLOSERED AREA

Tight seals are essential for control of oxygen; preferably they should be made of incombustible material, such as brick, tile, or concrete, well hitched into ribs, floor, and roof. They should be built where the roof as well as the floor and ribs are sound, to reduce to a minimum leakage through the strata. Seals cannot be made completely airtight, but an effort should be made to make them as tight as possible. If there are excessive leaks around and through the seals or if there are cracks or breaks to the surface or overlying measures, effort to control oxygen and extinguish the fire will be futile. There should be a constant decrease of oxygen content in the samples collected from behind fire seals; and if this does not occur, it usually can be attributed to leaky stoppings or breaks in the strata or coal that permit ingress of air. Sometimes the oxygen will be reduced rapidly and consistently and then, with slight fluctuations, remain almost stationary. This condition, also, usually can be traced to the same cause. In both cases the stoppings should be examined carefully and an extra effort made to close any leaks. If the stoppings are leaky or the fire is likely to burn around stoppings that have been erected, it may be advisable to erect double stoppings. When double stoppings are erected, if possible they should be about 15 or 20 feet apart. Stoppings should be inspected frequently and any cracks in or around them repaired promptly. Provisions should be made for collecting air samples and taking water-gage readings by
placing pipes with suitable valves, reducers, etc., in one or more of the stoppings.

**INFLUENCE OF BAROMETRIC PRESSURE AND TEMPERATURE ON ENCLOSED AREA**

Barometric pressure has an effect on sealed areas, as it is largely responsible for the so-called “breathing” in and out. If barometric pressure increases in excess of the pressure behind seals, air is likely to enter the sealed region. Similarly, if barometric pressure decreases to less than that of the sealed region outward, leakage through or around the stoppings will result. The latter condition assists materially in reducing the oxygen and aids dissipation of carbon monoxide. Frequently sufficient pressure is developed in the enclosed region to offset any increase in barometric pressure, and when these ideal conditions prevail there will be continual outward pressure against the seals. Facilities for taking water-gage observations should be provided in one or more of the stoppings that enclose the fire region. When the water gage indicates that pressure is increasing in the fire region, the excess pressure may be “bled off” under a water seal if it is found advisable to do so.

The temperature on the outside of the mine probably has more influence than the barometric pressure on a sealed fire region. It is known, from observation, that when the temperature outside of the mine is considerably lower than the mine temperature, inward pressure on the fire seals is likely to occur, and that if the outside temperature is somewhat higher than the mine temperature outward pressure will result.

It is not known definitely what causes outside temperature changes to affect the pressure on a sealed fire area, but it is well known that increase or decrease in the temperature of gas or air will result in increase or decrease in volume and pressure. Therefore, it is logical to assume that warming or cooling of the outside air as it circulates through the mine causes increase or decrease in volume and pressure, which, in turn, results in either inward or outward pressure (inward if the outside temperature is lower and outward if it is higher) on the stoppings of a sealed region.

The temperature within the sealed territory also probably has considerable influence on the direction of pressure (inward or outward) on the stoppings. When a fire is extinguished within a sealed region and cooling progresses, there is a decrease in volume and pressure inside the sealed region, which undoubtedly will cause inward pressure on the stoppings until the inside and outside pressures are equalized.

Temperatures at the site of seals are not indicative necessarily of the temperature within the sealed territory; however, if any of the stoppings are hot or warm, it is evident that the temperature within the sealed region is high.

**EFFECT OF VENTILATION ON SEALED AREA**

The location of the fire region with respect to the system of ventilation may have considerable effect on the extinguishment of a fire. For example, an area sealed where the air current passes on two sides (one side being intake and the other return) as against an area
sealed on one side only (such as a pair of entries) will cause a difference in potential that may induce leakage through the stoppings and strata. A condition of this sort may prolong the extinguishment of the fire. The fire at the Oakmont mine of the Hillman Coal & Coke Co., in Pennsylvania, which is referred to later, is a striking example of how circulation of air through the sealed area prevented extinguishment of a fire for approximately 6 months because different parts of the sealed panel (fig. 20) were under different amounts of suction or negative pressure. From figure 20 it can be seen that an
entire panel was sealed and that it was possible to travel and make observations on all sides of the sealed region.

The seals enclosing the fire region consisted of 13-inch brick walls laid in cement mortar, exceptionally well hitched in the roof, ribs, and floor, and as nearly airtight as stoppings ordinarily can be made. When a consistent reduction of oxygen did not occur, double stoppings were erected along the main face entries, but this had little or no effect. As indicated by arrows on the sketch, when the region was sealed the ventilation consisted of an intake air current from one split traveling along the stoppings on the main face entries and the top of the sealed panel and a return air current from another split traveling along the opposite side and bottom of the panel. The difference in potential between the two air currents was about 3 inches water gage.

Under the conditions described, the oxygen was not reduced below 4.20 percent for about 6 months. A change was made in the ventilation by erecting a stopping and opening a door (indicated on sketch by circle in lower right hand corner), thereby taking air from the split on the main-face entries around the opposite side and bottom of the sealed panel as well as along the main-face entries and top of the panel; the result was that the same air pressure was exerted on all sides of the sealed region, and a gradual and consistent reduction of oxygen to below 1 percent followed in about 4 months. Further details on the oxygen content and other gases within the sealed territory are discussed later in this publication.

**SAMPLING AND ANALYSIS OF ATMOSPHERE UNDER SEAL**

It is of the utmost importance that proper sampling and accurate analyses be made of the fire gases so they indicate unquestionably the composition of the gases in the sealed area. Samples should be collected from behind stoppings only when the pressure is outward, as samples collected when there is inward pressure almost invariably are inaccurate and consequently are not representative of the sealed atmosphere. Samples from fire areas should be collected at least once every 24 hours during the first few days. Later, when the analysis shows by the reduction of oxygen that the stoppings are tight, the samples can be collected at longer intervals, possibly once a week or even longer.

There are at least three methods that can be employed in collecting samples—by vacuum tube, water displacement, and air displacement (using an aspirator bulb or pump). Of the three methods, the vacuum tube is preferable, as it is more easily sealed, can be stored almost indefinitely, and is best adapted for shipment. After samples have been collected they should be analyzed accurately. Portable field apparatus can be used where extreme accuracy is not essential. The portable modified Orsat apparatus is accurate to approximately 0.20 in the reading of the percent by volume of the gases analyzed. If greater accuracy is desired, the samples should be sent to a laboratory equipped for accurate work, where analysis as accurate as 0.01 or 0.02 can be made.

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PROCEDURE IN SEALING AND UNSEALING MINE FIRES

COMPOSITION OF FIRE GASES IN SEALED AREA

Correct interpretation of the composition of fire gases is vital in determining when it is reasonably safe to break the seals. It has long been recognized that the presence of carbon monoxide indicates active or recently active fire; the absence of carbon monoxide is not a safe criterion that the fire has been extinguished, but rather that flame and more or less active combustion have ceased. Especially does this hold where a large area is under seal, in which case carbon monoxide may be lost through dilution or may not be diffused throughout the entire territory. It is not safe to unseal any fire, with a view to ventilating the affected region, until the carbon monoxide has disappeared. Even after the carbon monoxide has disappeared it is advisable to allow ample additional time for the heated material and strata to cool before the sealed area is opened and ventilated; in fact, it may be necessary to delay unsealing for several months before the region cools enough to be reopened with safety.

Although few if any scientific data are available, it is generally recognized that at least three causes contribute to the diminution of oxygen within a sealed territory. These are displacement of oxygen by methane emissions from the coal or strata, absorption of oxygen by exposed coal surfaces and timber, and consumption of oxygen by combustion.

Before an attempt is made to unseal a fire, the oxygen in the sealed region should be low enough to prevent the possible ignition of explosive gases; but before this condition obtains, active combustion naturally will have ceased. In their experiments with methane-air mixtures, Jones and Perrott 12 found that when the oxygen is reduced to 12.1 percent flame propagation and explosion are impossible, no matter what proportions of methane are present. The gases found in sealed regions contain, in addition to varying percentages of methane, small quantities of hydrogen, carbon monoxide, and other combustible gases. The extent to which oxygen should be reduced under these conditions depends upon the relative quantities of hydrogen, carbon monoxide, and other combustible gases present. The data available on this subject indicate that when the oxygen in a sealed fire territory is reduced to 4 percent, there is little if any likelihood of an explosion. However, it is desirable that the oxygen be reduced to at least 3 percent and preferably below 1 percent before an attempt is made to unseal, as the lower the percentages, the greater the safety from dilution of the gas due to changes in barometric pressure or leaks during unsealing.

The influence of carbon dioxide contained in fire gases is shown by Coward and Hartwell, 13 who have determined that 25 percent or more of carbon dioxide is required to render methane-air mixtures incapable of flame propagation. They also found that there was a marked decrease in the upper explosive limit (15 percent) of methane-air mixtures and a comparatively slow increase in the lower limit (5

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UNSEALING MINE FIRES

percent) by the addition of varying percentages of carbon dioxide. The practical application of these experiments is to show that the explosion limits of methane-air mixtures in mines are unaffected by carbon dioxide and that the latter has little, if any, influence, other than the displacement of oxygen, in the extinguishment of a fire under seal because the percentage of carbon dioxide found in fire gases rarely exceeds 6 percent at the time for unsealing.

TYPICAL EXAMPLES OF MINE-FIRE GASES

Tables 1 and 2 give analyses of fire gases taken from the Horning and Oakmont mines near Pittsburgh, Pa.

Horning mine.—On February 5, 1926, a section of the Horning mine of the Pittsburgh Terminal Coal Corporation, Pennsylvania, was sealed following a fire and two subsequent explosions. It will be noted from table 1 that the first sample, taken at noon on February 5, showed 13.4 percent of oxygen. Subsequent samples taken at frequent intervals showed a constant and somewhat rapid reduction in the oxygen content from the first sample to No. 17 (4.2 percent) collected 10:50 p. m., February 9. This reduction from 13.4 to 4.2 percent probably was hastened by a gas feeder which was the source of the original fire and the subsequent explosions. The gas issuing from the feeder caused increased pressure in the enclosed area, which in turn reduced the oxygen content in the air by outward leakage of the atmosphere under seal through the stopping that enclosed the fire. This is clearly brought out by a study of table 1, which shows 11.3 percent of methane on February 5 and 33.6 percent on February 9. Recovery of the affected region was begun by a system of air locks on the 10th and completed on the 15th. The maximum oxygen increase during this period, while rescue crews were at work, was only 1.4 percent, and the methane increased from 34.2 to 51.3 percent. Seals were placed in the entry where the fire originated on February 15, and no attempt was made to ventilate the affected region until March 13. At this time the oxygen and carbon monoxide contents were 0.2 and 0.1 percent, respectively. An exploration trip by rescue crews on March 13 proved that the fire had been extinguished. A full account of this occurrence is given under “Procedure used in unsealing Horning mine fire.”

TABLE 1.—Analyses of air samples taken at the Horning mine fire and explosion (fire and explosion occurred Feb. 3, 1926)

| Sample | Date, 1926 | Hour | Location          | CO₂ | O₂ | CO | CH₄ | N₂ | Water gage in stopping Barometer in mine |
|--------|------------|------|-------------------|-----|----|----|-----|----|-------------------------------|---|-------------------|---|
| 1      | Feb. 5     | 12 noon | 8-face stopping  | 2.4 | 13.4 | 0.8 | 11.3 | 72.1 |                                     |   |                  |
| 2      | do         | 4:45 p. m. | do             | 2.8 | 12.3 | 1.3 | 11.7 | 72.0 |                                     |   |                  |
| 3      | do         | 11:30 p. m. | do             | 3.0 | 11.3 | 1.3 | 13.1 | 71.3 |                                     |   |                  |
| 4      | Feb. 6     | 5:30 a. m. | do             | 4.1 | 9.8  | 1.4 | 15.8 | 68.9 |                                     |   |                  |
| 5      | do         | 12 noon    | do             | 5.0 | 8.9  | 1.4 | 18.2 | 67.0 |                                     |   |                  |
| 6      | do         | 6:45 p. m. | do             | 4.7 | 8.3  | 1.6 | 19.4 | 66.0 | .65                               |   |                  |
| 7      | do         | 11:45 p. m. | do             | 4.6 | 8.0  | 1.4 | 20.5 | 65.5 | .7                              |   |                  |
| 8      | Feb. 7     | 8:45 a. m. | do             | 5.2 | 7.0  | 1.6 | 23.1 | 63.1 | .7                              |   |                  |
| 9      | do         | 4:45 p. m. | do             | 4.7 | 6.4  | 1.4 | 24.9 | 62.4 | 1.2                            |   |                  |
| 10     | do         | 11:05 p. m. | do            | 4.5 | 6.2  | 1.5 | 26.6 | 61.2 | 2.3                           |   |                  |
| 11     | do         | 3 a. m.    | do             | 4.3 | 6.1  | 1.5 | 27.3 | 60.9 | 1.45                          |   | 29.25               |
| 12     | do         | 11:30 a. m. | do            | 4.6 | 5.5  | 1.5 | 29.9 | 68.5 | 1.8                        |   | 20.17               |
| 13     | do         | 5:50 p. m. | do             | 4.6 | 5.2  | 1.4 | 30.7 | 68.1 | 1.6                        |   |                  |
### Oakmont mine.

On January 14, 1925, a section (see fig. 20) of the Oakmont mine was sealed following the discovery of fire. It will be observed from table 2 that the first sample, collected on January 15, contained 15.45 percent of oxygen and another sample, collected on the 24th, contained 4.2 percent. This was the lowest oxygen content shown over a long period, as a sample collected on March 6 contained 5.2 percent. When the oxygen content showed no reduction, the stoppings surrounding the fire area were reinforced and every effort was made to stop leakage of air. Water-gage readings taken at the stoppings on the intake and return sides of the area showed about 3 inches inward pressure on the intake side and about 3 inches outward pressure on the return side. On April 4, in order to ascertain definitely conditions within the sealed area, rescue crews explored behind the seals adjacent to the fire. The explorations were made through air locks A and B, thus admitting a minimum amount of oxygen. When the

### Table 1.—Analysis of air samples taken at the Horning mine fire and explosion (fire and explosion occurred Feb. 3, 1926)—Continued

<table>
<thead>
<tr>
<th>Sample</th>
<th>Date, 1926</th>
<th>Hour</th>
<th>Location</th>
<th>Percent by volume</th>
<th>Water gage in stopping</th>
<th>Barometer in mine</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CO₂</td>
<td>O₂</td>
<td>CO</td>
</tr>
<tr>
<td>14</td>
<td>Feb. 9</td>
<td>1 a.m.</td>
<td>8-face stopping</td>
<td>4.5</td>
<td>5.0</td>
<td>1.3</td>
</tr>
<tr>
<td>15</td>
<td>do</td>
<td>11 a.m.</td>
<td>do</td>
<td>4.6</td>
<td>4.7</td>
<td>1.3</td>
</tr>
<tr>
<td>16</td>
<td>do</td>
<td>6:10 p.m.</td>
<td>do</td>
<td>4.3</td>
<td>4.4</td>
<td>1.1</td>
</tr>
<tr>
<td>17</td>
<td>do</td>
<td>10:50 p.m.</td>
<td>do</td>
<td>4.6</td>
<td>4.2</td>
<td>1.5</td>
</tr>
<tr>
<td>18</td>
<td>Feb. 10</td>
<td>3:45 a.m.</td>
<td>do</td>
<td>4.0</td>
<td>5.7</td>
<td>1.3</td>
</tr>
<tr>
<td>19</td>
<td>do</td>
<td>6 a.m.</td>
<td>160 feet inby seal on ninth face</td>
<td>3.6</td>
<td>4.2</td>
<td>1.6</td>
</tr>
<tr>
<td>20</td>
<td>do</td>
<td>8:40 a.m.</td>
<td>Where stopping No. 3 is built</td>
<td>3.7</td>
<td>3.9</td>
<td>1.3</td>
</tr>
<tr>
<td>21</td>
<td>do</td>
<td>10:20 p.m.</td>
<td>No. 3 stopping after stopping was built</td>
<td>3.8</td>
<td>5.5</td>
<td>1.3</td>
</tr>
<tr>
<td>22</td>
<td>do</td>
<td>do</td>
<td>No. 2 stopping after stopping was built</td>
<td>3.8</td>
<td>5.6</td>
<td>1.2</td>
</tr>
<tr>
<td>23</td>
<td>do</td>
<td>11 p.m.</td>
<td>From valve in 8-face stopping</td>
<td>4.0</td>
<td>3.9</td>
<td>1.6</td>
</tr>
<tr>
<td>24</td>
<td>Feb. 11</td>
<td>7:30 a.m.</td>
<td>Ninth face 27 feet inby breakthrough No. 7</td>
<td>4.2</td>
<td>3.6</td>
<td>1.4</td>
</tr>
<tr>
<td>25</td>
<td>do</td>
<td>11 a.m.</td>
<td>From valve in 8-face stopping</td>
<td>3.9</td>
<td>3.4</td>
<td>1.3</td>
</tr>
<tr>
<td>26</td>
<td>do</td>
<td>11:45 a.m.</td>
<td>Ninth face 15 feet inby crosscut where No. 7 stopping is to be built</td>
<td>4.0</td>
<td>3.5</td>
<td>1.2</td>
</tr>
<tr>
<td>27</td>
<td>do</td>
<td>do</td>
<td>Eighth face 15 feet inby crosscut where No. 7 stopping is to be built</td>
<td>4.0</td>
<td>3.5</td>
<td>1.3</td>
</tr>
<tr>
<td>28</td>
<td>Feb. 12</td>
<td>12:15 a.m.</td>
<td>Ninth face 15 butt first advance</td>
<td>4.0</td>
<td>3.2</td>
<td>1.4</td>
</tr>
<tr>
<td>29</td>
<td>Feb. 13</td>
<td>4:45 a.m.</td>
<td>15 butt between Nos. 1 and 2 rooms</td>
<td>3.5</td>
<td>4.5</td>
<td>1.2</td>
</tr>
<tr>
<td>30</td>
<td>do</td>
<td>9:50 a.m.</td>
<td>Outside stopping in 16 butt</td>
<td>3.5</td>
<td>4.8</td>
<td>1.1</td>
</tr>
<tr>
<td>31</td>
<td>do</td>
<td>1 p.m.</td>
<td>15 butt between Nos. 1 and 2 rooms</td>
<td>3.6</td>
<td>4.8</td>
<td>1.1</td>
</tr>
<tr>
<td>32</td>
<td>do</td>
<td>5 p.m.</td>
<td>Intersection of No. 2 room 15 butt</td>
<td>3.5</td>
<td>4.7</td>
<td>1.0</td>
</tr>
<tr>
<td>33</td>
<td>do</td>
<td>10:30 p.m.</td>
<td>Inside chute 16 butt 100 feet from face</td>
<td>3.1</td>
<td>4.6</td>
<td>1.5</td>
</tr>
<tr>
<td>34</td>
<td>Feb. 14</td>
<td>2 a.m.</td>
<td>Inside chute 16 butt 100 feet from face</td>
<td>3.1</td>
<td>5.6</td>
<td>0.9</td>
</tr>
<tr>
<td>35</td>
<td>do</td>
<td>10 p.m.</td>
<td>15 butt upper chute</td>
<td>2.8</td>
<td>6.0</td>
<td>0.4</td>
</tr>
<tr>
<td>36</td>
<td>Feb. 15</td>
<td>5:50 p.m.</td>
<td>Eighth face 250 feet inby 16 butt</td>
<td>2.8</td>
<td>4.7</td>
<td>0.5</td>
</tr>
<tr>
<td>37</td>
<td>Mar. 11</td>
<td>1:30 p.m.</td>
<td>Through seal 16 butt</td>
<td>2.9</td>
<td>1.1</td>
<td>1.1</td>
</tr>
<tr>
<td>38</td>
<td>Mar. 13</td>
<td>7:40 p.m.</td>
<td>do</td>
<td>2.8</td>
<td>1.2</td>
<td>1.1</td>
</tr>
</tbody>
</table>

1 Seals were broken about 4 hours after sample 17 was taken.
2 Last body recovered on Feb. 15 at 11:03 p.m.
3 Sample 57 taken 25 days after recovery of bodies.
4 Sample 58 taken 27 days after recovery of bodies.
5 Seals broken and area ventilated night of Mar. 13, 1925.
UNSEALING MINE FIRES 53

rescue crew found unmistakable indications of fire within air lock B, the area was resealed and flooded. The flooding was afterwards found to have been unsuccessful, owing to differences in elevation within the sealed area. Table 2 shows that after resealing, samples contained slightly more oxygen, and virtually no reduction was effected until after July 10. The increase in oxygen probably was due largely to water being pumped to the sealed region. The carbon monoxide did not decrease materially until after June 11. On June 12 the ventilation was changed by building a stopping in the return from No. 10 butt and by opening trapdoor E on the intake airway outby No. 10 butt. The change in ventilation placed an equal pressure on all stoppings that enclosed the fire region, and the water-gage readings at all stoppings became zero. The carbon monoxide also began to decrease rapidly. A sample taken on August 22 showed 2.1 percent of oxygen, and samples taken on October 8 showed 0.8 percent at No. 20 butt and 0.4 percent at No. 10 butt, respectively. On October 15 the territory was explored and, as no indications of fire were found, it was reventilated.

Table 2.—Analyses of air samples taken in Oakmont mine sealed area (fire discovered Jan. 14, 1925)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Date, 1925</th>
<th>Location, butt No.</th>
<th>CO₂</th>
<th>O₂</th>
<th>H₂</th>
<th>CO</th>
<th>CH₄</th>
<th>N₂</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Jan. 15</td>
<td>19 return</td>
<td>2.22</td>
<td>15.45</td>
<td>0.0</td>
<td>0.66</td>
<td>1.44</td>
<td>70.23</td>
<td>First sample after stoppings were completed.</td>
</tr>
<tr>
<td>2</td>
<td>Jan. 24</td>
<td>do</td>
<td>4.5</td>
<td>4.2</td>
<td>1.4</td>
<td>1.2</td>
<td>3.8</td>
<td>84.9</td>
<td>Hydrogen probably due to burning material falling in water.</td>
</tr>
<tr>
<td>3</td>
<td>Feb. 9</td>
<td>do</td>
<td>4.8</td>
<td>5.5</td>
<td>0.6</td>
<td>1.4</td>
<td>5.4</td>
<td>82.3</td>
<td>Explored back of stopping, Apr. 4, 1925.</td>
</tr>
<tr>
<td>4</td>
<td>Feb. 26</td>
<td>do</td>
<td>5.4</td>
<td>4.9</td>
<td>0.0</td>
<td>1.6</td>
<td>7.1</td>
<td>81.0</td>
<td>Started to flood behind seals.</td>
</tr>
<tr>
<td>5</td>
<td>Mar. 6</td>
<td>do</td>
<td>5.2</td>
<td>5.7</td>
<td>0.0</td>
<td>1.1</td>
<td>7.3</td>
<td>80.7</td>
<td>Unable to get sample at 19 butt closed by water.</td>
</tr>
<tr>
<td>6</td>
<td>Apr. 8</td>
<td>do</td>
<td>5.8</td>
<td>5.5</td>
<td>0.0</td>
<td>1.3</td>
<td>7.9</td>
<td>79.5</td>
<td>Large volume of air pumped out before taking sample.</td>
</tr>
<tr>
<td>7</td>
<td>Apr. 16</td>
<td>10 return</td>
<td>3.7</td>
<td>5.5</td>
<td>0.0</td>
<td>1.4</td>
<td>8.6</td>
<td>81.5</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>do</td>
<td>20 intake</td>
<td>5.0</td>
<td>6.1</td>
<td>0.0</td>
<td>8.3</td>
<td>79.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>May 5</td>
<td>10 return</td>
<td>3.8</td>
<td>6.1</td>
<td>0.0</td>
<td>3.9</td>
<td>9.2</td>
<td>80.6</td>
<td>Do.</td>
</tr>
<tr>
<td>10</td>
<td>do</td>
<td>20 intake</td>
<td>3.5</td>
<td>7.5</td>
<td>0.0</td>
<td>4.0</td>
<td>10.5</td>
<td>78.1</td>
<td>Hydrogen probably due to water reaching fire in roof.</td>
</tr>
<tr>
<td>11</td>
<td>June 11</td>
<td>10 return</td>
<td>2.4</td>
<td>5.9</td>
<td>0.0</td>
<td>1.1</td>
<td>10.7</td>
<td>81.2</td>
<td>Do.</td>
</tr>
<tr>
<td>12</td>
<td>do</td>
<td>20 intake</td>
<td>3.9</td>
<td>8.5</td>
<td>0.0</td>
<td>18.5</td>
<td>68.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>June 22</td>
<td>10 return</td>
<td>2.7</td>
<td>7.7</td>
<td>0.0</td>
<td>10.1</td>
<td>11.1</td>
<td>78.47</td>
<td>Considerable pumping to get sample.</td>
</tr>
<tr>
<td>14</td>
<td>do</td>
<td>20 intake</td>
<td>3.8</td>
<td>6.1</td>
<td>0.0</td>
<td>0.9</td>
<td>19.8</td>
<td>70.3</td>
<td>Stopping under pressure.</td>
</tr>
<tr>
<td>15</td>
<td>July 10</td>
<td>10 return</td>
<td>3.1</td>
<td>6.9</td>
<td>0.0</td>
<td>0.3</td>
<td>18.7</td>
<td>79.3</td>
<td>Do.</td>
</tr>
<tr>
<td>16</td>
<td>do</td>
<td>20 intake</td>
<td>3.1</td>
<td>4.7</td>
<td>0.0</td>
<td>0.3</td>
<td>18.6</td>
<td>73.6</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Aug. 22</td>
<td>10 return</td>
<td>4.3</td>
<td>2.1</td>
<td>0.0</td>
<td>0.0</td>
<td>17.1</td>
<td>76.5</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Oct. 8</td>
<td>do</td>
<td>4.6</td>
<td>8.0</td>
<td>0.0</td>
<td>0.9</td>
<td>20.8</td>
<td>73.8</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>do</td>
<td>20 intake</td>
<td>3.3</td>
<td>4.4</td>
<td>0.0</td>
<td>26.4</td>
<td>69.9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 Seals broken and area ventilated night of Oct. 15, 1925.

CONCLUSIONS REGARDING TIME TO UNSEAL FIRES

In addition to the factors just mentioned, which generally govern the time for unsealing, there may be local factors that will necessitate careful scrutiny, such as the proximity of gas wells to fire areas, the positions of boreholes, the extent of the region under seal, and temperature within the sealed area. Ordinarily, more time will be required before unsealing a large area than a small area; especially is this true if the seals in the former are poorly placed.
PROCEDURE IN SEALING AND UNSEALING MINE FIRES

Very careful consideration obviously must be given to all of the foregoing factors in the proper determination of the time for unsealing, as an error in any of them may necessitate resealing and may result in disaster.

PREPARATION FOR UNSEALING

The successful opening of any fire area necessitates certain preparatory work; an organization composed of oxygen breathing-apparatus and gas-mask crews and other necessary personnel, with the equipment and material required, should be assembled and ready for work. Most certainly no person should be in the mine during unsealing except those engaged in the work and absolutely needed.

VENTILATION AND ROCK DUSTING

Necessary adjustments in ventilation should be to direct fire gases from the sealed region into the main return. All return airways that are to be utilized for carrying the fire gases to the outside of the mine should be inspected carefully and necessary arrangements made to confine the gases therein and prevent their circulation or accumulation in other portions of the mine. In bituminous coal mines all entries and crosscuts leading to and from the fire region should be coated heavily with rock dust at and for a considerable distance outby the seals that are to be opened.

FAN AND FAN ATTENDANT

An attendant should be at the mine fan to see that it is operating efficiently, and if its slows down or stops, immediately to warn the men engaged in the unsealing work. If the fan is electrically driven, gases from the sealed region should be prevented from coming in contact with the motor or other electrical equipment used for operating the fan. Guards should be placed to prevent smoking in the vicinity of an exhaust fan and to prevent unauthorized persons from approaching the fan while fire gases are being moved, or any opening from which fire gases are issuing when a force fan is used.

ELECTRIC POWER CUTOFF

It is essential that electric power be cut off the section of a coal mine in which a fire is sealed even before the actual work of unsealing is undertaken. Moreover, when the seals are opened, it is absolutely necessary that the electric power be cut off from at least the section containing the fire and the return airways to obviate possible ignition of gas through arcs or sparks. Where possible, it is highly desirable to cut all electric current from the entire mine during unsealing operations.

METHODS OF UNSEALING MINE FIRES

The method to be used for the recovery of a fire region must be planned and outlined in detail before the seals are broken. In general, two systems may be employed—(1) recovery in successive blocks by means of air locks and (2) reventilation after there is conclusive evidence that the fire has been extinguished. When the sealed area is extensive, the fire inaccessible, or the exigencies of the case necessitate the removal of bodies from a previous explosion, the region should be
recovered in sections by using air locks and advancing to a point where observations can be made or the bodies recovered. Air locks consist of two stoppings 10 or 15 feet apart equipped with doors through which oxygen breathing-apparatus crews can enter or take material into the sealed area. One door of the air lock is kept closed at all times. After an air lock is completed, the crews work through it and erect another air lock about 200 to 500 feet inby and perform such other work as may be required for reventilation of the region between air locks. The distance between locks depends largely on conditions encountered, such as ease of travel, height of passageway, work to be done, etc. As an area between air locks is recovered, the locks outby should be removed. After the air locks have been advanced close enough to the seat of the fire to permit observations to be made, it may be possible to load out heated material through the air locks, as was done at the Sunnyside mine, Sunnyside, Utah.¹⁴ When the area under seal is relatively small, so that it can be explored by rescue crews under reasonably safe conditions and when there is every indication that the fire has been extinguished, the region should be reventilated and the fire gases removed as quickly as possible, preferably with all persons out of the mine.

RECOVERING SEALED REGION BY USE OF AIR LOCKS

If it has been decided to recover part or all of a sealed fire area by the use of air locks, a tightly constructed air lock should be erected at a convenient distance from one of the seals on the intake side of the fire area.

After the oxygen has been reduced considerably below the point where an explosion is possible, if explosive gas is being generated within the sealed area, or below the point where a flame can burn, if no explosive gas is present (12.10 and 16.25 percent, respectively), air-locking operations can be started. To provide an adequate safety factor, before the seals are broken the oxygen should be reduced at least to 6 percent when explosive gas is present and at least to 10 percent or lower when no gas is present.

After a suitable air lock has been erected, proper organization and adequate equipment and material have been provided, and all other necessary arrangements have been completed, an oxygen breathing-apparatus crew fully equipped for the work at hand and supported by a fully equipped reserve crew should enter the air lock and remove the seal.

After the seal has been removed, an advance oxygen breathing-apparatus crew with another crew in reserve, using a life line or portable telephone, should explore to the point where the next air lock is to be erected, a distance generally not to exceed 500 feet. This exploring crew should observe general conditions, take temperature readings, collect an air sample to check previous analyses, measure for material required to construct the inby stopping of the next air lock, and then return to the fresh-air base. An apparatus crew or crews, with a reserve crew at the fresh-air base, should construct a stopping with a door in it at the place previously selected for the

next air lock; should erect necessary stopping in crosscuts or other openings on the intake side and on the parallel entry or entries on the return side opposite the point selected for the air lock to insure resealing of the inby area; and should examine any unexplored parts of the isolated area for possible fires. Then crews should be withdrawn from inside the air locks and a seal on the return side should be opened by an apparatus crew; the air-lock doors on the intake side should be opened and air admitted to reventilate the area inside the air locks. Brattice-cloth stoppings should be erected in open crosscuts on the return side to advance fresh air to the last crosscut, which should be left open to provide a return.

The quantity of air admitted through the air lock should be regulated so that the return will be kept below the lowest explosive limit. After the newly sealed area has been reventilated to form the next air lock, fresh-air men should erect a tightly constructed stopping with a door in it at a suitable distance outby the one previously built, and erect suitable stoppers to replace the temporary brattice-cloth stoppers placed in openings on the return side.

In like manner, with the exception that no seal need be broken on the intake side, advances should be made by successive blocks until the entire area is recovered. As the work progresses, frequent analyses should be made to determine the composition of fire gases within the sealed area. The oxygen should be kept under control and within safe limits at all times. It is imperative that the oxygen be kept as low as possible at all times to allow for limited infiltration of air as the work progresses.

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PROCEDURE USED IN UNSEALING HORNING MINE

A section (see fig. 21) of the Horning mine of the Pittsburgh Terminal Coal Co., Pennsylvania, was sealed after an explosion that occurred during the sealing of a fire on February 3, 1926, and killed 20 men. Three bodies had been recovered by rescue crews when a second explosion occurred, making it extremely dangerous to attempt to recover the other 17 victims. After careful deliberation by those in charge of the situation, it was decided to seal the affected region and attempt to recover the bodies by erecting a system of air locks when the oxygen content of the sealed area had been reduced to 4 percent.

The sealed region is known as the fourth section south and consisted of three face entries (Nos. 7, 8, and 9 south) and two butt entries leading from the face entries (known as Nos. 15 and 16 butt right entries). The face entries extended approximately 1,000 feet from the seals to their faces, and at a point about 500 feet from the seals the two butt entries were turned off from the face entries. The butt entries extended about 500 feet from the face entries. Nine rooms, ranging from about 12 to 120 feet in depth, were turned off No. 15 butt right; no rooms were turned off No. 16 butt. The total distance from the seals to the face of the butt entries was about 1,000 feet. The fire that caused the explosions was at the face of No. 16 butt right, and it was thought that nearly all of the entombed men would be found on Nos. 15 and 16 butt entries, which proved to be correct.
PROPOSED SCHEDULE

Step No. 1. It is agreed by all present that 3-ply canvas stoppings be erected at point indicated by Nos. 1, 2, and 3.

Step No. 2. After stoppings 1, 2, and 3 are erected fresh air may be conducted to the crosscut in which stopping No. 3 is erected.

Step No. 3. Erect match-lumber stoppings where canvas stoppings 1, 2, and 3 are located; doors to be placed in stoppings 2 and 3, also a pipe in stopping No. 2 for the purpose of obtaining air samples.

Step No. 4. Erect a match-lumber stopping at point indicated by 4; remove stopping No. 3 at break, and erect door in original stopping on road No. 8.

Step No. 5. Erect stopping No. 6 in road No. 8 at point indicated, next erect stopping No. 8 on road No. 7 as indicated, next open doors in original stopping on road No. 7.

Step No. 6. Erect 3-ply canvas in crosscut at point indicated by the figure 7, then proceed to erect a lock such as that erected at point No. 2 at a point that may be decided upon after examination of the ground has been made.

Step No. 7. The final air lock to be located on road No. 9 at the point indicated by the letter A on the map.

Legend

- Stoppings before breaking seals
- Stoppings to be erected
- Location of body
- Where stoppings were built
- Air sample
- Door
- Ventilation

FIGURE 21. Sketch of procedure of recovery work, Horn mining mine.

Stopping No. 4, not marked, is represented by the double horizontal line above and to the left of No. 3.
Construction of seals.—The permanent brick and tile seals were in Nos. 7, 8, and 9 face entries and were completed about 8 a. m., February 5. A pipe was placed in the stopping on No. 8 face entry to collect air samples and take water-gage readings. The pipe was equipped with valves, and one end of it was immersed in a tub of water to release pressure if desired.

Analysis of atmosphere behind seals 3½ hours after sealing.—The first air sample was taken from behind the seals at about 11:30 a. m., February 5, and gave the following analysis: 2.4 percent of CO₂, 13.4 percent of O₂, 0.8 percent of CO, 11.3 percent of CH₄, and 72.1 percent of N₂. Additional air samples were taken at about 8-hour intervals and analyzed by a modified Orsat apparatus on a Bureau of Mines rescue car by chemists from the Pittsburgh Experiment Station of the bureau.

Water-gage and barometer readings were taken frequently and a close check kept on the pressure behind the stoppings. When the pressure behind the seals reached 2.25 inches water gage the valve in the stopping on No. 8 face entry was opened and the pressure “bled off” through the pipe placed in the tub to prevent it from increasing. At no time during the recovery operations did the water gage show that the sealed area was under suction. However, on one or two occasions the outward pressure was very slight, due to a rising barometer.

Construction of stoppings and air locks.—The period necessary for the oxygen to be reduced was utilized to good advantage in building stoppings for ventilation purposes outby the sealed region, obtaining and placing materials close to the seals, and rock-dusting all entries and crosscuts in proximity to the sealed territory. During this time an air lock with a line wood brattice was also built outby the stopping on No. 9 face entry.

The air lock constructed on No. 9 face entry and those mentioned later consisted of two stoppings 15 to 20 feet apart. These were constructed of matched white pine and all openings and cracks were filled with stiff mud. Each stopping had a large 2- by 5-foot door on hinges, a means of fastening, and a 2- by 2-foot slide door. A line brattice of matched lumber or brattice cloth was built midway in the entry within the air lock from one stopping to the other. The large doors of the air lock were used for ingress and egress of rescue crews and for handling materials; the small doors, when opened, served as the return from the ninth face entry when ventilation was established to the next air lock. By building air locks of this kind, a crew wearing oxygen breathing apparatus could pass through the first door, close this door, and open the inside door, pass through, close the second door also, and carry on their work. On returning, the inside door was closed before the outer one was opened. One door was thus kept closed at all times, and as far as possible air was prevented from entering the sealed region from the outside.

All stoppings and air locks were built with white pine 2- by 4-inch frames and uprights, matched lumber, and copper nails. Copper hammers also were used in all construction work. As already mentioned, cracks and openings in the stoppings were filled with mud to reduce leakage as much as possible.

Analysis of atmosphere behind seals 4 days after sealing.—At 6:10 p. m. February 9, or about 4½ days after the permanent seals had been
erected, analysis of the air was as follows: 4.3 percent of CO₂, 4.4 percent of O₂, 1.1 percent of CO, 36.5 percent of CH₄, and 53.7 percent of N₂. It was then decided that, as by the time all necessary arrangements could be made the oxygen probably would be reduced to about 4 percent, the seals would be broken when the 11 p.m. shift went underground. Analysis of a sample taken at 10:50 p.m. gave 4.6 percent of CO₂, 4.2 percent of O₂, 1.5 percent of CO, 36.5 percent of CH₄, and 53.2 percent of N₂. By the time all of the necessary arrangements were made and the seal was removed in No. 9 face entry it was 2:45 a.m., and the oxygen was probably reduced to 4 percent or less.

Details of reopening sealed area and recovery of bodies.—Three 8-hour shifts were employed. Each shift included one man in charge, two or three assistants, two State mine inspectors, four rescue teams of five men each wearing oxygen breathing apparatus, and laborers, drivers, and others.

The organization at the fresh-air base consisted of one man in charge, one or more assistants, two State mine inspectors, and the rescue crews. Before entering the air lock, each apparatus crew was given detailed instructions on the work the members were to perform.

Whenever one or more apparatus crews were working or exploring, they were backed up with a reserve crew stationed within the air lock. Not more than five permissible flame safety lamps for gas detection were allowed underground on each 8-hour shift. Permissible electric cap lamps and flashlights were used exclusively for illumination.

After breaking the seal in No. 9 face entry, a crew wearing apparatus, supported by another crew in fresh air, passed through the first air lock and advanced approximately 225 feet in No. 9 face entry. The construction of another air lock was started at this point. When this air lock was completed, two stoppings were erected in breakthroughs between Nos. 8 and 9 face entries. An air sample taken at this time gave 5.2 percent of oxygen between the two air locks. At the completion of this work the first air lock was opened and a line canvas extended from No. 1 to No. 2 air lock, thereby conducting fresh air to the outer door of No. 2 air lock. Following this, stoppings were erected on Nos. 7 and 8 face entries by working through No. 2 air lock. When these were completed, an exploration was made between the seals and the newly erected stoppings in Nos. 7 and 8 face entries. These two entries were then ventilated to the new stoppings. One body was recovered during this work in No. 8 face entry.

Next, a crew advanced about 250 feet more in No. 9 face entry or just out by No. 15 butt. An air sample was obtained at this point and the erection of No. 3 air lock begun. The analysis of this sample gave 4 percent of CO₂, 3.2 percent of O₂, 1.4 percent of CO, 46.6 percent of CH₄, and 44.8 percent of N₂.

On completion of the air lock, two stoppings were again erected between Nos. 8 and 9 face entries, and a line brattice was extended and air conducted from No. 2 to No. 3 air lock. From this air lock stoppings were erected in Nos. 7 and 8 face entries and No. 16 butt entry and an air lock in No. 15 butt between Nos. 1 and 2 rooms. One body was recovered in a breakthrough between Nos. 15 and 16 butts during this operation.
The only difficulty encountered in the erection of stoppings was in connection with the two constructed at this point in Nos. 7 and 8 face entries. A trip of cars and a motor were found in No. 8 face entry. The cars were wrecked and jammed in the entry at the place where the plan of procedure indicated the stoppings were to be erected. It became necessary to change the location of these two stoppings from the original plan and to erect them approximately 50 feet in by. Before the stoppings were erected it was necessary to cut one of the wrecked cars to permit the apparatus men to work around the wrecked trip in safety.

After the face entries and No. 16 butt were ventilated to the newly erected stoppings and No. 15 butt to the air lock, a crew was sent on an exploration trip into Nos. 15 and 16 butt entries and found the bodies of 14 men, which left one body still to be found. All of the bodies except the one that had not been located were recovered and passed through the air lock by 5 a. m., February 14. Analysis of an air sample taken in by the last breakthrough in No. 16 butt at 2 a. m., when search for bodies was being made, showed 3.1 percent of CO₂, 5.6 percent of O₂, 0.9 percent of CO, 45.6 percent of CH₄, and 44.8 percent of N₂.

After Nos. 7, 8, and 9 face entries were explored and ventilated to their faces, and Nos. 15 and 16 butts were again explored to locate the remaining body, it was finally found and recovered the following night (11:03 p. m.) from under a fall of slate at the face of No. 6 room off No. 15 butt. After the last body was recovered on February 15, permanent seals of concrete blocks with tile centers were erected out by the air lock in No. 15 butt and the stopping in No. 16 butt. This region was left sealed until March 13, when it was unsealed and reventilated.

**Final unsealing of Horning fire region.**—When unsealing the final area of the Horning mine in which the fire had been, a base of operations was established out by the seal in No. 15 butt, and all necessary materials and equipment required for the unsealing were placed at the fresh-air base. Three rescue crews were employed for this work. Nos. 1 and 2 crews, respectively, with No. 3 crew in reserve, broke the intake seal and entered the air lock, which had been erected and used during the recovery of the bodies. No. 1 crew advanced to the face of No. 16 butt, tested for carbon monoxide with a detector, and placed a maximum and minimum thermometer at what was considered to be the hottest place. No. 2 crew placed a maximum and minimum thermometer in the first breakthrough in by the seal on No. 15 butt and advanced to between rooms 8 and 9 in No. 15 butt. All crews then returned to the outside of the air lock and reported. No. 1 crew reported that the maximum and minimum thermometers placed at the face of No. 16 butt and in the first breakthrough inside the air lock read the same and that there was no indication of carbon monoxide or heat.

To check these observations, a second exploration trip was made. No. 2 crew went to the face of No. 16 butt and No. 3 crew to between rooms 8 and 9 in No. 15 butt. No. 1 crew acted as reserve. Similar observations and reports were made. A sample taken at the seal of No. 16 butt on March 11 showed 2.9 percent of CO₂, 0.1 percent of O₂, 0.1 percent of CO, 88.8 percent of CH₄, and 8.1 percent of
N₂, and with this favorable analysis it was decided to reventilate the area. A line brattice was extended through the crosscut outby the seals in Nos. 15 and 16 butts, and the seal in No. 16 butt was opened by a rescue crew. The doors in the air locks in No. 15 butt were then opened and the fire gases removed as quickly as possible. The rescue crews then entered the area and removed the standing fire gases in the rooms off No. 15 butt.

**Outstanding factors in successful unsealing of Horning fire area.**—Twelve crews of five men each, wearing oxygen breathing apparatus, built all air locks and stoppings used in recovering the bodies. In addition they made exploration trips and carried all bodies to the fresh-air base. Three crews were used later in unsealing the final block on March 13, 1926. No long trips were attempted at any time; 300 to 400 feet was the maximum distance the crews traveled or worked ahead of fresh air. All of the crews engaged in the operation did exceptionally good work, and too much can not be said for their training, obedience, willingness, endurance, and courage. The entire project was carried on without injury to anyone and with but little apparatus difficulty. This can be attributed largely to a well-planned, well-organized, and well-conducted procedure drawn up before the work was started and followed by strict adherence to the plan at outlined. The air sampling and analysis, which showed the condition behind the stoppings at all times, were important factors in the successful conclusion of the work. The experienced men composing the apparatus crews and the men in charge of the different shifts also aided materially in successfully completing the task.

Air locks were employed, also, to unseal mine fires at the Sunnyside mine of the Utah Fuel Co., Sunnyside, Utah, in 1920; the Rockwood mine of the Roane Coal & Iron Co., Rockwood, Tenn., in 1925; the Connellsville No. 1 mine of the Connellsville By-Product Coal Co., Pursglove, W. Va., in 1927; and the Woodward mine of the Glen Alden Coal Co., Edwardsville, Pa., in 1927.

**RECOVERING A SEALED AREA BY REVENTILATION**

When a decision has been made to recover a sealed region by direct ventilation, an air lock should be constructed, preferably near the intake seal. A rescue crew using a life line and fully equipped for the work at hand should break the seal, enter, observe conditions, take temperature readings and air samples, and return to the fresh-air base. If the observations and examination of the affected region have shown that conditions are favorable, the return seal should be broken by an apparatus crew; the air lock should then be opened to admit air. The area should be ventilated, but the combustible gases in the main return, if feasible, should be kept below the lowest explosive limit. The unsealing of the final fire area of the Horning mine on March 13, 1926, is a good example of unsealing by direct ventilation.

If an explosion is expected, it is advisable that all men be out of the mine before the air is actually directed into the sealed area. Some automatic arrangement should be employed to allow ample time for all persons to reach the surface before the fire gases are actually moved. A reasonable period should be allowed for the gases to be...
removed, and frequent samplings should be made of the return air from the mine; the time for any person to enter should be governed by the quality of the return air. This may be tested by installing a continuous methane recorder in the main return from the mine or by systematic periodic sampling and analyzing. If the workings under seal are extensive, it probably will be advisable for crews equipped with oxygen breathing apparatus or possibly with gas masks to re-enter the mine and completely clear any standing fire gases out of the fire area.

**RECOVERY PROCEDURE FOLLOWING MINE EXPLOSIONS**

An efficient organization, proper and adequate equipment and materials, and proper procedure are of prime importance in conducting rescue and recovery operations safely after a mine explosion. Improper procedure may sacrifice possible chance of rescuing persons left alive in a mine after an explosion and may also result in loss of life of men engaged in recovery work. As soon as possible the fan should be inspected and kept running with an attendant in charge; electric current should be cut off from the mine; mine entrances guarded and roped off; and a checking in and out system established. Rescue and recovery crews, with other personnel and necessary equipment and material, should be assembled promptly as indicated in previous discussion of organization, equipment, and materials.

**EXAMINATION OF MINE OPENINGS**

Before exploring is begun, a preliminary examination should be made of all openings and escapeways, as men overcome by afterdamp may be found near openings.

If the explosion has occurred in a shaft mine and the cage, signaling devices, and headframe have been damaged or destroyed, the safest and most convenient shaft compartment should be used for descent. It may be necessary to use a bucket for descending the shaft to make a preliminary examination around the shaft bottom; however, a cage should be made available if at all feasible, as little progress can be made with a bucket, except possible in the early stages of the investigation preparatory to doing effective recovery work.

**ESTABLISHING VENTILATION**

If the ventilating fan has not been destroyed or damaged so it cannot be operated, it should be kept running; with the fan running normally, ventilation will be established only to the point where stoppings have been destroyed by the force of the explosion. The ventilating current should not be reversed without good reason and then only on written orders to those in charge; this is of vital importance, particularly if any live men are known to be in the mine. If it is impossible to operate the fan, repairs or replacements should be made immediately as little or no recovery progress can be made without adequate ventilation. Advantage should be taken of any natural ventilation that may be established to make a preliminary examination of the region of mine openings and for a short distance inside the mine.
When the necessary organization has been formed, equipment and materials assembled, and ventilation established, exploration of the mine should be started.

The officials in charge of the shift should check the crews going underground (fig. 22) to see that everyone is properly equipped for the work at hand and that only persons whose services may be of definite use are allowed to go into the mine.

On entering the mine, the rescue and recovery crews should advance in fresh air to the point where ventilation has been destroyed and establish a fresh-air base outby that point.
ESTABLISHING TELEPHONE COMMUNICATION

Portable telephones may be used to advantage to keep in touch with outside when crews are advancing. However, a standard-type telephone (preferably permissible type, if available) connected with the outside should be installed at the fresh-air base, with an operator always present. As recovery work progresses, the telephone system should be extended and additional telephones installed so that a telephone will always be in reasonable proximity to the advance crews, though ordinary-type telephones should not be installed or left where they are likely to come in contact with explosive gas.

DUTIES OF RESCUE AND RECOVERY CREWS

Owing to the different nature of their duties and requirements, underground crews often are designated more or less indiscriminately as rescue crews and recovery crews. Rescue crews comprise men equipped with gas masks or oxygen breathing apparatus and especially trained and equipped to make explorations, perform work in irrespirable air, and, when the occasion arises, to rescue living men. Recovery crews are composed of brattice men, men for handling and transporting material and bodies, drivers, telephone attendants, timbermen, trackmen, road cleaners, and other miscellaneous personnel.

Rescue crews work in close cooperation with recovery crews by making explorations ahead of fresh air to reach live men, locate bodies, test the mine air, look for fires, and erect stoppings where respiratory protection is required. Men wearing heavy breathing apparatus should not transport bodies except in an emergency, and then only for short distances; those who have not worn oxygen breathing apparatus are prone to ask apparatus men to perform duties that should not be required of those who do this very arduous and hazardous work.

Men in charge of the shifts, the fresh-air base, or other officials and members of rescue crews should guard against unnecessary breathing of afterdamp to prevent impairment of their usefulness and judgment. Members of recovery crews not equipped with adequate respiratory protection should not be permitted to go ahead of fresh air, as they may be overcome or their efficiency reduced by breathing the harmful gases likely to be encountered in mine rescue and recovery work.

EXPLORATIONS AHEAD OF FRESH AIR

After a fresh-air base has been established, exploring should be done ahead of fresh air by rescue crews wearing oxygen breathing apparatus or possibly gas masks if it is known that the masks may be used safely to look for live men and fires, locate bodies, and observe conditions. It is always advisable to make short trips ahead of fresh air (about 250 to 400 feet), as experience has shown that more can be accomplished and the work carried on more safely by this method than by long and dangerous trips far in advance of fresh air. Long exploration trips should not be made unless they are absolutely necessary to save life or to do other work positively required for the continuance of recovery operations. Exploration trips ahead of fresh air may be performed largely by gas-mask crews if it is fairly defi-
nitely known that masks can be used safely. Oxygen breathing-apparatus crews should be held in reserve to support gas-mask crews or for use where gas masks cannot be worn with safety. When gas-mask or oxygen breathing-apparatus crews are working ahead of fresh air, another oxygen breathing-apparatus crew, fully equipped with apparatus adequately charged and in good condition, always should be held in reserve at the fresh-air base (fig. 23).

Before starting an exploration ahead of fresh air, the crew should examine carefully their apparatus, life line, and other equipment to insure that everything is in good condition; they should be given...
definite instructions by the man in charge of the fresh-air base as
to the extent of the trip, distance to travel, things to observe, and
time to be taken in making the trip.

On leaving the fresh-air base the rescue crew should travel a short
distance, probably 50 to 100 feet, ahead of fresh air and stop long
enough to make sure that their apparatus are airtight and func-
tioning properly. Then, carrying a life line or batteryless-type
portable telephone and wire for giving signals, they should proceed
slowly, in single file, about 6 feet apart. They should examine the
roof and roadway; mark with chalk the direction of travel, with
arrows pointing to the fresh-air base; mark the name or initials of
the crew captain or name of the crew, and the day, month, and year
on the faces of all rooms, entries, etc., and at the farthest point of
the trip; and carefully note conditions and report their observations
to the man in charge when they return to the fresh-air base.

During exploration trips ahead of fresh air, rescue crews should
act in accordance with previous instructions and training, having
regard at all times for their own personal safety. Good judgment
and common sense are required to conduct exploratory work ahead
of fresh air safely and efficiently.

**RESTORING VENTILATION**

Ventilation must be restored throughout the mine for the recovery
of all men and bodies and for the removal of afterdamp.

If no fires are found after exploring ahead of fresh air for some
distance, possibly through several breakthroughs or crosscuts, to
ascertain conditions, the next step is to erect the necessary stoppings
to ventilate the explored region.

**CONSTRUCTIONS OF STOPPINGS**

If an explosion has affected a large area, many temporary stoppings
will be required to restore ventilation. Temporary stoppings should
be made as nearly airtight as possible and strong enough to withstand
the pressure that will be required to carry air to the face regions.
Such material as may be available should be used to construct tem-
porary stoppings. Brattice cloth or canvas of good grade has num-
erous advantages (fig. 24), but burlap, muslin, and bed ticking may
be used until better material is available.

Temporary stoppings near mine openings or other places where
they will be subjected to considerable air pressure should be con-
structed of two to four plies of brattice cloth, depending on the size
of the stopping and the distance air must be carried. Temporary
stoppings should be set far enough (at least 4 to 6 feet) inside of
crosscuts or other openings to leave space for the later construction
of stronger and tighter stoppings.

As soon as possible, semipermanent stoppings of boards or stronger
material, or permanent stoppings of bricks, cement blocks, tile, etc.,
should be erected to replace temporary stoppings, particularly where
the temporary stoppings are under considerable air pressure.

Details of the construction of temporary and permanent stop-
pings are described in the section on sealing mine fires.

As recovery work progresses, a large number of temporary stoppings
may be in use, and to insure that these are kept tight and in good
condition, men should be appointed on each shift to patrol and keep the temporary stoppings as nearly airtight as possible.

CONTROL OF VENTILATION

The procedure of alternately exploring ahead of fresh air and advancing the air by erecting temporary stoppings should be con-

continued until the entire region affected by the explosion has been recovered.

In ventilating any portion of a mine after an explosion, the after-
damp should be conducted to the outside by the most direct route.
Permitting the poisonous gases to travel through other sections of a mine may seriously endanger the lives of survivors of the explosion or persons engaged in the rescue or recovery work.

Safe practice requires that currents of air be conducted so the ventilation will always be under the control of the man in charge of the shift and the paths the air is traveling will always be known definitely; it is extremely dangerous after an explosion, especially in a gassy mine, to permit air to travel over or through unexplored portions of the mine. Unless this vital precaution is taken, an explosive mixture of gas may be brought in contact with a fire, thereby causing another explosion, possibly with disastrous effects; this has occurred in several cases.

All sections, entries, rooms, and other open accessible workings, etc., if possible should be cleared of afterdamp as work advances; if this is not done, fires may be bratticed off and reach a serious stage before discovery; or explosive, asphyxiating, or poisonous gases may seep from bratticed-off areas, enter the ventilating current outby the point where recovery work is in progress, and seriously affect members of the rescue or recovery crews or possibly cause an explosion.

Line brattice will be required for ventilating faces of entries and rooms or when it is necessary to split the air current in entries. If a brattice is required for a considerable distance, it should be erected by setting posts about 8 to 12 feet apart in the center or on one side of the passageway; a board should be nailed along the top of the posts and the top of the brattice cloth nailed to it; probably the bottom end of the brattice cloth also should be nailed to a board or it can be held in place by lumps of coal, pieces of slate, etc.

When a short-line brattice is required to clean out the face of a working place, as from the last crosscut to the face of the place, sometimes especially in low workings or workings of medium height, it can be erected quickly by having a number of men hold the brattice cloth in place instead of fastening it on posts. A roll of brattice cloth long enough to reach the desired distance should be held upright in the passageway where the outby end of the line brattice is to start; several feet of the cloth should then be unrolled and held by one of the men, while others advance toward the face unrolling the cloth and holding the unrolled portion to the roof as the roll is advanced, until the ventilating current reaches and clears the face of afterdamp. After the face has been ventilated the cloth can be dropped, rolled up, and used again. Where it can be used, this method is preferable to setting posts and nailing the brattice cloth, as it is much quicker.

EXAMINING FOR AND EXTINGUISHING FIRES

Frequently smoldering fires (which may be dormant for as long as several days and fanned to life by the entrance of fresh air), and sometimes active fires are found after mine explosions. Doors, timbers, gob, dust, brattice cloth, and coal are likely to be set on fire by the heat and flame of the explosion. Such fires are extremely dangerous in gassy mines, as they may ignite an explosive mixture of gas. When exploring ahead of fresh air, rescue crews should make careful examination for fires; and as ventilation is advanced,
frequent inspections should be made of the return-air currents for smoke or heated air.

If fires are found while rescue crews are exploring ahead of fresh air, they should be extinguished if possible with water, rock dust, or fire extinguishers before the fresh air is advanced to the fire. When the fire is of such proportions or is so inaccessible that it cannot be extinguished, it should be sealed promptly and effectively.

If smoke and an explosive mixture of gas are encountered and the location of the fire is unknown, it is advisable to seal the region containing the fire, or the entire mine, at once. When the latter is done,

![Diagram showing section of the Everettville mine with air locks used.](image)

**Figure 25.**—Section of the Everettville mine in which air locks were used.

...to continue recovery operations it may be necessary to use air locks to work around the fire area, as was done following an explosion in Federal No. 3 mine of the New England Fuel & Transportation Co., Everettville, W. Va., in May 1927.

In this instance, smoke and an explosive mixture of gas were encountered shortly after recovery work was started, and the safety of the men engaged in the work demanded that the entire mine be sealed until further plans could be made. It was decided to continue recovery operations by air-locking around the area containing the fire. Figure 25 shows a section of this mine and gives a comprehensive idea of how the work was conducted. Undoubtedly, it was the largest air-locking job ever attempted in a bituminous mine; approximately
35 oxygen breathing-apparatus crews, working in 6-hour shifts, were employed for a week, and 14 air locks and about 50 stoppings were required to work around the region containing the fire. Details regarding the construction of air locks and procedure to follow have been explained previously in the discussion on the recovery of bodies and unsealing the fire following an explosion in the Horning mine; and the procedure for sealing a fire is described in the section dealing with that subject.

**RESCUE AND REMOVAL OF LIVE MEN**

Sometimes live men are found after an explosion. Usually they are suffering from poisonous or asphyxiating gases, burns, or injuries. Men found affected or overcome in an atmosphere containing after-damp should have an oxygen breathing apparatus (preferably a half-hour type) placed on them and should be carried to fresh air as soon as possible. If sufficient oxygen is present to support life (a lighted flame safety lamp will indicate this), a gas mask or self-rescuer probably can be used safely instead of an oxygen breathing apparatus.

As soon as possible after live men are brought to fresh air, they should be given oxygen to breathe. The oxygen should be administered (preferably by means of an inhaler) for at least 30 minutes to remove carbon monoxide from the victim’s blood. If rescued men are breathing slowly, or not at all, but show indications of life, artificial respiration should be administered in conjunction with oxygen until they are revived or until it is known definitely that it will be impossible to revive them.

Occasionally, live men are found behind barricades erected to protect themselves from afterdamp. Great care should be exercised, if the region immediately outside the barricade is in an irrespirable atmosphere, to prevent poisonous or noxious gases from entering the barricade while men are being rescued. If fresh air can be advanced to the barricade in a short time, this is desirable and should be done before the barricade is opened. If it is impossible to conduct fresh air to the barricade in a reasonably short time, provision should be made to admit the least possible amount of irrespirable air behind the barricade when it is opened by erecting a tight canvas stopping, with a small opening covered with canvas, a short distance (about 10 to 15 feet) out by the barricade to allow sufficient room to set a stretcher lengthwise between the stopping and barricade.

After the stopping has been erected, an opening large enough to admit an open stretcher should be made in the barricade and covered immediately with canvas. After these arrangements have been completed, the following procedure should be used in rescuing men from behind the barricade.

If all or some of the men found behind barricades can walk, they should be provided with the necessary protective equipment, such as an oxygen breathing apparatus (preferably half-hour type), or, if a flame safety lamp will burn outside the barricade, a gas mask or self-rescuer, and led or assisted to fresh air. If they are unable to walk, four men with a stretcher should pass through the stopping, admitting as little air as possible, and enter the space between the stopping and barricade. They should then pass through the barricade, again admitting the least possible amount of air, and enter the space behind
the barricade. A man (depending on the condition of the men behind the barricade) should be selected for rescue, provided with the necessary protective equipment, loaded on a stretcher, taken through the opening in the barricade (the opening then being tightly closed), then through the stopping (this opening then being tightly closed), and finally carried to fresh air by the shortest and quickest route. These operations should be repeated until all of the men behind the barricade have been rescued. Every effort should be made to prevent the admission of irrespirable air through either the stopping or barricade while men are entering or leaving. If reasonable care is exercised, several men can be rescued from behind a barricade with the admission of only a small amount of the harmful air into the barricaded space.

All rescued men, whether from behind barricades or otherwise, on reaching fresh air should be given first-aid treatment, consisting of artificial respiration, if required, administration of oxygen, treatment for shock, and dressing of wounds, burns, or other injuries. Rescued men should be well covered and wrapped with blankets or quilts before being taken outside, and those unable to walk should be placed on stretchers and carried or hauled to the outside. All rescued men should be taken to an emergency or permanent hospital for further observation and treatment.

**HANDLING BODIES**

After an explosion, dead bodies may be found in various parts of the mine. Some bodies may have no injuries or mutilations, while others may be badly damaged, dismembered, or decomposed.

All bodies should be wrapped in brattice cloth or canvas by the recovery crews and transported to the morgue. When bodies are not recovered for several days they should be sprayed well with a disinfectant, such as a strong solution of creolin or lysol, before being touched, handled, or wrapped. A tag bearing the serial number and the location where the body was found should be attached to each body. If the location has not been marked previously on the roof or rib, this should be done by the recovery crew. The location, position of the body, and check number or name also should be marked on the mine map. Nothing should be removed from a body while it is in the mine, except in the presence of witnesses, and then only if a written record is made of the material removed. Any material removed from a body should be given to a responsible person to be turned over to the man in charge of the morgue or to relatives of the victim. Bodies received at the morgue should have a morgue number assigned and should be identified if possible.

The official in charge of the morgue should make a record of tags attached by the recovery crews and the check number, if checks are found on the body, and a record of clothing, shoes or boots, money, watch, or other jewelry found on the body; a description of the features, color of hair and eyes, height, weight, and teeth, old scars or fractures, and probable age of the victim.

All clothing and other articles removed from a body should be wrapped in cloth or canvas, tied securely with a tag inside and the morgue number outside, and delivered to the coroner or the relatives of the deceased.
PROCEDURE IN SEALING AND UNSEALING MINE FIRES

SETTING TIMBERS

Many timbers may be knocked out by the force of the explosion and the roof may be weakened by the heat. As a protection to rescue and recovery crews and others who are required to travel roadways, manways, and entries, timber crews should remove dangerous roof and set necessary timbers as soon as possible.

CLEARING ROADWAYS

Roadways should be cleared of falls and debris and necessary repairs made to the haulage tracks as soon as possible after an explosion. The transportation of material and bodies and the recovery work in general will be facilitated greatly if the haulage tracks and haulage equipment are made available for use. Storage-battery locomotives (permissible type), horses, or mules should be provided for motive power. Trolley-pole or cable-reel locomotives should not be used because of the hazards of igniting explosive gas.

PREPARATION FOR RESUMING OPERATIONS

After the area affected by a mine explosion has been explored, the bodies removed, fires (if any) extinguished or sealed, and the inspectors and mine officials have completed their investigations, crews should be set to work building permanent stoppings, cleaning haulage roads and air courses, and making such other repairs as may be necessary to safe operation of the mine.

When all necessary repairs and changes have been made, the State mine inspector should examine the mine before regular work is started and if in his judgment the mine is in safe condition, operations may be resumed.

RESCUE AND RECOVERY OPERATIONS COURSE

Since 1925 the Bureau of Mines has conducted a course of instruction in rescue and recovery operations (commonly called advanced mine rescue training) for mine officials, State mine inspectors, and members of oxygen breathing-apparatus crews, based on information contained in Miners' Circulars 33, 34, 35, and this publication (Miners' Circular 36). About 3 days are spent on the surface (fig. 26) discussing mine gases and describing, using, and testing the equipment and devices employed in rescue and recovery work. About 2 days are spent in underground work in training class members in methods of actual recovery. A hypothetical fire or explosion is assumed to have occurred in a section of a mine involving at least a pair of entries and several rooms.

The instructor should visit the area to be in the practice recovery operations before the underground work is started, and should arrange the details of the problem by marking with chalk or by placing signs, such as "methane", "carbon monoxide", "depleted atmosphere", "fire", "barricaded men", "dead men", "falls", etc., at suitable places. When an explosion is involved in the problem, stoppings, doors, and overcasts should be marked as "blown out" to show that ventilation has been destroyed; various other indications of force and violence also should be indicated. Figure 27 gives a
Figure 26.—Class in rescue and recovery operations receiving instruction in use of equipment.
Crew A explored as shown, after which fresh-air base was advanced to here. Crew B explored until safety lamp went out, returned to fresh-air base. Crews C and D explored as shown after crew B returned. Crews A and B built stoppers to restore ventilation in the area. Live men barricaded, located by crew D, were rescued by placing oxygen breathing apparatus on men and conducting them to fresh air before moving gas in rooms 15 and 16.

Picture 27.—Problem in rescue and recovery work after explosion.
After surface conditions have been determined, the crews should proceed underground to the point where it is assumed the fresh-air

Many different problems may be devised, depending on the natural and assumed conditions and the arrangement of problem.

PROCEDURE BEFORE GOING UNDERGROUND

On the day before starting the underground problem, the mine officials and oxygen breathing-apparatus and gas-mask crews, composing the class in rescue and recovery operations, should be notified to report at a predetermined place at a specified time. In some instances, companies having a rather large organization or a mine rescue organization composed of several companies arrange a problem without previously informing the men who are to take part in the recovery work; the crews and other personnel are notified (usually early in the morning) as though an actual mine fire or explosion had occurred; this method, used occasionally, gives an idea of the time required to assemble officials and crews and to form a temporary organization in an actual emergency. The class members should form crews and assemble and test oxygen breathing apparatus, gas masks, gas-detecting devices, and other equipment and materials required for the underground work.

SURFACE ARRANGEMENTS

Before going underground, after an assumed or actual mine fire or explosion, officials and crews should obtain information on surface conditions and make necessary arrangements to insure their own safety, about as follows:

1. Power should be cut off all electric lines leading underground.
2. It should be ascertained that the fan is in operation.
3. A man should be stationed at the fan to see that it continues to run and to keep unauthorized persons away from it.
4. A checking in and out system should be established.
5. All mine entrances should be roped off and guarded.
6. Everyone who goes underground should be searched for smokers' articles, matches, and pocket lighters, and no one except authorized persons should be allowed to go underground.
7. Permissible electric cap lamps, flashlights, and flame safety lamps only should be permitted underground.
8. All flame safety lamps should be examined and tested carefully before being taken underground.
9. A minimum number of flame safety lamps should be used.
10. A map of the mine, showing openings, development, and other important features, should be obtained.
11. Information should be obtained from the mine superintendent and other mine officials regarding underground conditions.
12. Personnel, equipment, and material should be checked carefully to ascertain that everything required is at hand.

PROCEDURE AFTER GOING UNDERGROUND

After surface conditions have been determined, the crews should proceed underground to the point where it is assumed the fresh-air
PROCEDURE IN SEALING AND UNSEALING MINE FIRES

base is to be established, and all information obtained on the section of the mine in which the explosion is assumed to have occurred should be reviewed.

The oxygen breathing-apparatus and gas-mask crews are assigned their duties; one crew is designated to explore ahead of fresh air to a predetermined point, and another is selected to act as reserve crew. After the crew captains have received their instructions, they should discuss their various duties, arrange their crews accordingly, and the captains of the crew about to explore and of the reserve crew should examine the apparatus of their crew members. After discussing details with his crew, the captain of the exploration crew should report to the man in charge of the fresh-air base that he is ready to proceed. Before the crew leaves, the instructor or man in charge of the fresh-air base should give the captain definite instructions as to the objects of the trip, observations the crew is to make, distance it is to travel, and the extent of the exploration. In addition, there should be a definite understanding with the crew captain as to the time of return of the crew to the fresh-air base.

FIRST EXPLORATION

After the captain has checked the apparatus of his crew and has had his own apparatus examined by one of the crew members to make sure each apparatus has sufficient oxygen and is properly adjusted, the crew should advance a short distance ahead of fresh air, stop long enough to ascertain that all apparatus are air-tight and functioning properly, and then proceed on the trip. The exploring crew should carry such equipment as a flame safety lamp, carbon monoxide detector or canary, chalk, writing pads and pencils, apparatus wrenches, and screw drivers. Crew members should use a life line or batteryless-type portable telephone and cable, proceed slowly in single file about 6 feet apart, and not become separated while making the exploration. They should examine the roof and roadway; mark with chalk the direction of travel, with arrows pointing to the fresh-air base; write the name or initials of the captain or name of the crew and the day, month, and year of the exploration on the face of rooms, entries, and at the farthest point of the trip; carefully observe conditions; and return and report their observations to the man in charge at the fresh-air base.

ADVANCING FRESH AIR

After the first exploration has been completed, observations made by the exploring crew are discussed by the man in charge of the fresh-air base, crew captains, and team members. If subsequent explorations are indicated before fresh air is advanced, they are made by a different crew in the same manner as the first exploration. When it is found advisable to restore ventilation by advancing fresh air, one of the crews, preferably the reserve crew, or a gas-mask crew, proceeds to erect temporary stoppings and perform such other work as may be required to advance the fresh air to a predetermined point, after which the fresh-air base is moved to this point.

The above procedure of exploring ahead of fresh air and advancing fresh air is continued by steps until the entire region known or as-
sumed to have been affected by the fire or explosion has been re-
covered. The solution of adverse conditions encountered in working
the problem, such as accumulations of methane, concentrations of
carbon monoxide, oxygen-depleted atmospheres, fires, barricades, etc.,
should be left largely to the crew captains, team members, and others
taking the training, the instructor only seeing that proper procedure
is followed.

It should be remembered always that certain safety precautions
must be impressed on the crews and others undergoing training to
prepare them as far as possible to handle and perform actual rescue
and recovery work.

RECOMMENDED RULES OF PROCEDURE

It should be emphasized that haphazard methods of procedure dur-
ing rescue and recovery operations after mine fires and explosions
have proven costly in both life and property. Proper procedure and
an efficient organization, with proper and adequate equipment and
materials, are vital in conducting rescue and recovery work safely.

The following important rules of procedure are recommended for
both assumed and actual rescue and recovery operations: 12

1. After the fan has been repaired and put in operation (if out of
commission), or if the fan has not been damaged, a fresh-air base
should be established underground and telephone communication es-
stablished to the outside. Portable army-type telephones may be used
for this purpose; however, standard mine telephones (preferably per-
missible type) are desirable. As work progresses and the fresh-air
base is advanced, the telephone system should be extended so that
telephone communication will always be available between the fresh-
air base and the outside.

2. The following is recommended for transmitting, receiving, and
standardizing signals from an exploring crew to the fresh-air base
and from the fresh-air base to the crew:

(a) Life line consisting of about 1,000 feet of sash cord wound on
a metal reel. Although this means of transmitting signals has been
used widely, however, it is far from satisfactory, as it is extremely
difficult to transmit signals clearly when the exploring crew is several
hundred feet away from the fresh-air base.

(b) Life-line signals that are used generally and for the purpose of
standardization should be as follows:

1 pull, "stop" if traveling or "all right" if at rest.
2 pulls, "advance."
3 pulls, "retreat" (from fresh-air base to team, "return at 
   once").
4 pulls, "distress."

Horn or other audible signals between crew members to be the
same.

The crew will keep the life line stretched or taut at all times to be
able to give or receive signals.

As the crew retreats toward the fresh-air base, the life line should be rewound on the reel.

(c) Portable telephones (batteryless type) are more efficient and satisfactory than the commonly used life line. When such telephones are being used, conversation between the crew captain and the fresh-air base should be limited to the absolute minimum necessary to carry on the work, as the crew captain is greatly handicapped in pronouncing words by the mouthpiece of the oxygen breathing apparatus, particularly those requiring use of the lips. Moreover, unless the crew captain has had considerable experience he may be inclined to talk unnecessarily and if not careful may cause leakage around his mouthpiece. Efforts at conversation by the crew captain should be confined largely, if not entirely, to the transmittal of signals of about the same extent as with a life line. The man at the fresh-air base may talk fairly freely to the crew captain, but not enough to confuse the latter in his work; the use of extended conversation is likely to slow up or handicap the work of the rescue crew.

The telephone cable should be rewound on the reel as the crew retreats toward the fresh-air base.

3. Before leaving the fresh-air base for exploration ahead of fresh air, the captain of an oxygen breathing-apparatus crew should do the following:

(a) Examine the apparatus of each crew member to see that it is properly adjusted and that the oxygen is turned on.

(b) Have a definite understanding with the man in charge of the fresh-air base as to the purpose of the trip, distance to travel, extent of the exploration, and time the crew is to return to the fresh-air base.

(c) Make sure that a reserve crew, with apparatus in good condition and an adequate supply of oxygen, is at the fresh-air base.

(d) Read the gage in each apparatus to determine that each member of his crew has an adequate supply of oxygen for the contemplated trip.

4. The minimum amount of oxygen for each apparatus, when an exploration is to be made ahead of fresh air, should be as follows:

(a) Two-hour-type apparatus only is recommended for explorations or other work ahead of fresh air in mines.

(b) Generally, it is inadvisable to start an extensive exploration with less than 1½ to 2 hours’ supply of oxygen in each apparatus.

(c) Obviously, it should be possible to complete any contemplated exploration trip and have at least 30 minutes’ oxygen supply remaining in each apparatus when the crew returns to the fresh-air base.

(d) Explorations ahead of fresh air with oxygen breathing apparatus should never be attempted with less than 30 minutes’ oxygen supply in each apparatus, except possibly in an effort to save life. However, even if life is involved, it should be reasonably certain that a sufficient supply of oxygen is available to permit the wearer of the apparatus to perform the required work and return to the fresh-air base before the oxygen supply is exhausted.

5. When exploring ahead of fresh air, crews should mark their course of travel, location of bodies, faces of rooms and entries, and the farthest point of the exploration. They also should carefully observe conditions and report to the man in charge on returning to the fresh-air base.
6. Exploration trips in coal mines should not be taken under the following conditions:

(a) In dense smoke, except with life line or portable telephones, and then only to save life or to turn valves or open or shut doors essential to recovery operations. Such trips should not extend longer than a few hundred feet, even when the route is fairly free of obstacles.

(b) When an explosion from gas is probable.

(c) When it is necessary to crawl on hands and knees because of low roof, slate falls, or other obstructions.

(d) When it is necessary to wade in water more than knee deep.

(e) When it is necessary to wade in water more than knee deep.

(f) When it is necessary to wade in water more than knee deep.

(g) With apparatus not adequately charged or in unsafe condition.

(h) Unless there is a reserve crew, fully equipped, at fresh-air base, except for very short trips.

7. Where possible, it is always advisable to make short trips (say, four or five breakthroughs) ahead of fresh air rather than long and dangerous explorations. Experience has shown that more can be accomplished and the work carried on more safely by this method than by trips far in advance of fresh air.

8. With a crew in proper physical condition and a reserve crew wearing apparatus at the fresh-air base, explorations in flat coal beds not to exceed 1,000 feet (2,000 feet per round trip) may be made in irrespirable gases if necessary, provided conditions are favorable. By favorable conditions are meant a nearly level unobstructed course, height 5 feet or more, good roof, and air clear or so nearly clear that vision of the crew is not materially obscured.

9. For pitching beds—that is, any beds that dip or rise more than 1 foot in 19 feet—the maximum distance of 1,000 feet recommended for flat beds should be reduced proportionally as the pitch increases. Explorations in advance of fresh air should never be undertaken on pitches of more than 30° on ladders or stairways unless there is reasonable assurance of saving life. In any event, apparatus wearers should take into consideration the difficulties encountered on steep or comparatively steep pitches and ladders or stairways, such as insecure footing, falls, and other obstructions. They should also be reasonably certain of their ability to return to fresh air unaided. The maximum distance apparatus wearers should travel in metal mines is given for clear atmospheres under various conditions, with the modifications to be made when an atmosphere is smoky or when high temperature and humidity are encountered:

(a) When the atmosphere is clear but gassy and the dip is less than 10°, the maximum distance to be traveled by apparatus wearers on unobstructed traveling should be 1,000 feet on advance and an equal distance in retreat. Where falls or other obstructions intervene, the distance allowable may be restricted to a few hundred feet each way or even less, depending on the dangers due to the falls or obstructions. Where water is much over 1 foot deep it is dangerous to go, even along a level road, much farther than 100 feet.

(b) Where the dip is more than 10° and less than about 25° and travel must be undertaken on the floor rather than on ladders or stairways, apparatus trips of over 500 feet each way are dangerous even in clear, cool atmospheres, especially if the floor is smooth.
Where obstructions are present, distances even shorter than 500 feet are dangerous. When the dip is over 25°, no apparatus trips should be attempted except on ladders or stairs.

(c) On inclined ladders (dip up to 60°), in good condition and with no obstructions (such as close platforms, sollars, walls, timbers, or falls), distances up to 200 feet are permissible in clear air, though safe removal from 200 feet of ladderway is difficult if an apparatus wearer becomes helpless. Where obstructions such as close platforms, timbers, or rock falls intervene in ladderways up to 60°, even shorter exploration with apparatus should not be attempted.

(d) On ladders sloping 60° to 90°, explorations with apparatus should not be attempted except in emergency, even though the circumstances as to clearness of atmosphere, obstructions, condition of ladders, etc., are favorable. In explorations under such emergency a rope should always be at hand for handling any member of the crew who may become ill or otherwise disabled. Under no circumstances should apparatus wearers climb over 200 feet of ladder at 60° to 90°; in general, 100 feet should be considered the maximum.

(e) In dense smoke, apparatus wearers should travel not more than a few hundred feet, even if no obstructions intervene; and to protect each apparatus wearer from falling into holes, he should have a cane or staff with which to feel his way. Similarly, travel in dense smoke on a dip of over 10°, whether on the floor or on a ladder or stairway, obstructed or unobstructed, should be restricted to short distances, preferably under 100 feet. The life line should always be used during exploration in smoky atmosphere. Goggles may be used to advantage in both clear and slightly smoky atmospheres; several methods are available to prevent fogging, the simplest being to hold within the goggle a little water to be run over the interior of the glass when it fogs.

(f) Temperature above 85° F. and humidity above 90 percent will limit further the allowable distances to be traveled by apparatus wearers, the higher the temperature and humidity the shorter the distance, with still greater limitation if the surrounding air or gases are motionless.