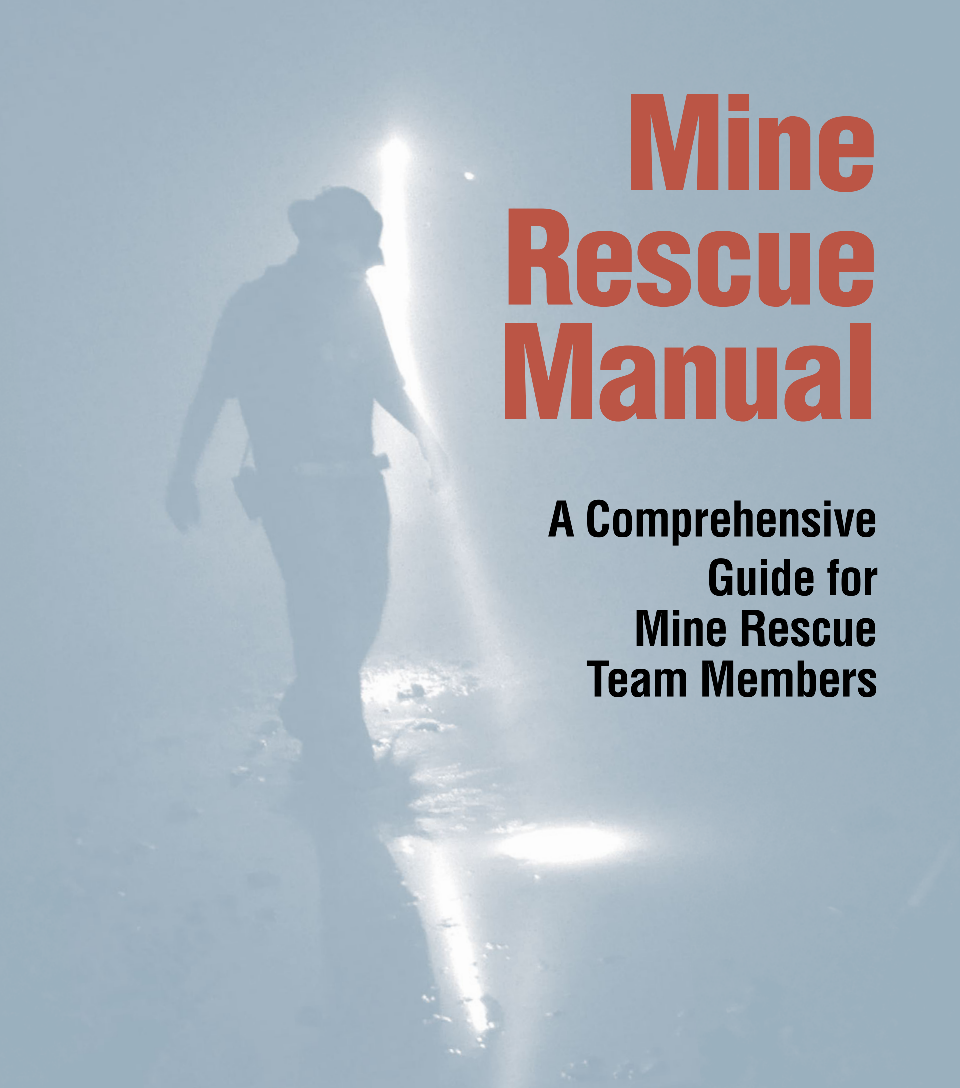

Mine Rescue Manual

A Comprehensive Guide for Mine Rescue Team Members

BY CHRIS ENRIGHT AND ROBERT L. FERRITER

SME

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Chris Enright and Robert L. Ferriter

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DEDICATION

The *Mine Rescue Manual* is dedicated to the six miners who lost their lives in the Crandall Canyon Mine Disaster in Utah on August 6, 2007, and the three underground mine rescuers who died while attempting to reach the trapped miners.

May their sacrifice be long remembered and their contributions to underground mine safety be multiplied many times by future miners and rescuers.

Contents

Preface

This *Mine Rescue Manual* originated as a project of the Mine Safety and Health Program (MSHP) at the Colorado School of Mines. It is based on the Mine Safety and Health Administration's (MSHA's) Instruction Guide 3027, *Mine Rescue Team Training: Metal and Nonmetal Mines*.

The content was originally created as a training aid for a Technical Rescue Engineer Company of the U.S. Army, as a functional supplement for MSHA's Mine Rescue Instruction Guide (IG) series for metal and nonmetal mines. With the initial success of the material for training the military unit, we continued development and writing of the manual to become an enhanced and updated version of MSHA's training materials for mine rescue teams. The curriculum was tested on members of the Colorado School of Mines Student Mine Rescue Team who helped us refine the content and applicability of the material to underground emergency response. The manual has been supplemented with industry best practices, field experience, and the most up-to-date supplemental references for specific subject matters. The authors approached SME with the completed material, and SME was enthusiastic about publishing a text on this subject.

This book is intended as a modernized supplement for the older MSHA IG series. New content has been added while shortening the original MSHA document.

IG 3027	Mine Rescue Manual
1. Surface Organization	Introduction
2. Mine Gases	The Team
3. Mine Ventilation	Surface Operations and Incident Command
4. Exploration	Equipment
5. Fires, Firefighting, and Exploration	Exploration
6. Rescue of Survivors and Recovery of Bodies	Firefighting
7. Mine Recovery	Ground Control
8. Mine Rescue Training Activities	Communication
	Gases and Ventilation
	Victims
	Mine Recovery
	Team Safety
	Additional Health Hazards
	Conclusion
	Additional Training

New content includes detailed material on team equipment, subject matter on ground control and communication, and details on team safety and additional hazards that exist underground. The "Surface Operations and Incident Command" section has been expanded to comply with the National Incident Management System (NIMS) using the common terminology as specified on a federal level for incident management. Information on mine gases has been updated with information from known sources, and content on victim management has been revised with more modern and accurate medical knowledge.

The authors thank the MSHP for its support and technical expertise in the creation of this text; particularly Nicole Henderson who assisted with the mine gases sections and helped with copy-editing; Christine Geier who contributed to the "Firefighting" section as well as construction and editing of the document; Erin Keogh who helped write the "Mine Recovery" section and assisted with document construction and editing; Leo Weiman who contributed to the "Ground Control" section and aided document construction and editing; and Wylie Keller, Chelsea Hudgen, Jerry Powers, Truman Beran, Alex Robles, and Michelle Reiher for their assistance with proofreading and editing.

About the Authors

Chris Enright is a training captain for the Colorado School of Mines (CSM) Mine Rescue Team, a training assistant at the CSM Mine Safety and Health Program, an emergency medical technician, recent graduate of CSM's Geology and Geological Engineering program, and primary author and compiler of this manual.

Robert L. Ferriter is a senior mine safety specialist for CSM's Mine Safety and Health Program and a faculty advisor for preparation of this manual. Ferriter earned an engineer of mines degree from CSM and a master of science degree in petroleum engineering. He has more than 30 years of professional experience. Ferriter has provided leadership for the startup of the CSM Mine Safety and Health Program and maintains a key advocacy role in miner safety and health, especially in first responder and rescue team training.

Introduction

TEAM OBJECTIVES

In mine rescue, like any type of recue, there are three primary objectives:

1. Team Safety
2. Rescue of Survivors
3. Protection of Property and the Environment

Team safety is always the first priority. If team members are injured or out of commission, they are unable to rescue survivors and become additional victims. Human life is always valued above property in a rescue situation, and team safety and survivor safety are the first two concerns for a team.

REGULATORY OVERSIGHT

Mine rescue teams are under the regulatory oversight of the Mine Safety and Health Administration (MSHA). Rules for equipment, team operations, team requirements, and more are contained in 30 CFR Part 49.

> **MSHA must be contacted within 15 minutes of a mine accident and may choose to take command over the incident.**
>
> **MSHA Mine Emergency Hotline:**
>
> **(800) 746-1553**

Additional regulatory oversight from a medical perspective is provided by the U.S. Department of Transportation's National Highway Traffic Safety Administration (NHTSA) emergency medical services (EMS) group, and by local physicians who are responsible for the creation of EMS protocols and standing orders. Mine rescue teams are often the first link in an EMS system treating patients from a mine site. Inquire locally to be certain about the regulations that may be applicable in your area.

MINE EMERGENCIES

A mine emergency is any sudden or unforeseen situation or incident that may:

- Endanger human life or cause significant injury
- Result in substantial damage to property
- Result in substantial environmental damage

Examples of mine emergencies include:

Inundation—Sudden or unplanned inundation of a mine (or part of a mine) with a liquid or gas. This may happen from breaking into old workings, inadvertent puncturing of a surface body of water, massive gas or water releases from storage tanks, and so on.

Roof Falls/Collapses/Outbursts—Rock falls from the roof or ribs/walls of the mine. This typically happens before the rock is bolted or grouted. Sudden collapse of large areas can cause a "bump" where a pressure wave is created as the rock displaces air.

Mine Fire—Fire not extinguished within 10 minutes of discovery (if underground) or within 30 minutes (if on the surface). Fires can be caused for many reasons, which will be discussed later.

Explosion—Explosions can be caused in three ways:

1. Rapid combustion of a gas or other fuel (coal dust)
2. Detonation of explosives
3. Failure of a pressure vessel (compressed gas tanks, hydraulic systems, etc.)

Other than the planned detonation of explosives, any other explosion is considered a mine emergency.

MSHA requires notification at (800) 746-1553 in the event of any of the following events at a mine site:

- Death
- Life-threatening injury
- Entrapment
- Unplanned inundation
- Ignition or explosion of gas or dust
- Unplanned fire
- Unplanned explosion
- Unplanned roof fall
- Disruption of regular mining activity for more than 1 hour
- Unstable condition that requires emergency action to prevent failure

- Damage to hoisting equipment in a shaft or slope
- Event at a mine that causes death or bodily injury to an individual not at the mine at the time the event occurs

These are termed *immediately reportable incidents*, and 30 CFR requires that MSHA be notified within 15 minutes of any of these events.

The Team

TEAM POSITIONS AND COMPOSITION

Each team is composed of at least six members—five who wear breathing apparatuses and at least one at the fresh air base (FAB). Each team member has his or her own specific assigned area of expertise, but should have a broad enough knowledge base to be aware of and understand the actions of other team members. In an emergency situation, a team member may be forced to assume a role other than for which he or she has trained, and a principle of "cross-training" is highly encouraged.

Team Captain

From the moment a team receives an emergency call to the end of the team demobilization, the team captain is responsible for leadership and command of the team.

The team captain is first to enter an area and is responsible for scaling and verifying the safety of ground conditions in areas the team enters. The team captain is also responsible for checking the status of the breathing apparatuses of team members and verifying the operation before the team enters the mine, 50 ft after entering the mine, and at 20-minute intervals beyond that time. See Table 1 for apparatus status checklist.

Gas Person

Table 1 Steps for an apparatus check

1. Straps
2. Facemask
3. Hoses
4. Gauge (reading)
5. Pack
6. Okay to proceed?

The gas person carries the team's multi-gas meters and is responsible for measuring the gases present upon entering an area. Measurements are conducted above the head, chest level, waist level, and near the knees across the entire drift to ensure proper sampling of air and an accurate measurement. The gas person is also responsible for having a working knowledge of mine gases and must know the explosive limits of the relevant gases in their operating area.

Map Person

The map person documents what is found, where it is found, the condition and time of find, and relays this information either to the co-captain or to the FAB. He or she documents all the findings of the team and collect the data to help guide future decisions and document the situation when the team entered.

Medic

The team's medic is responsible for patient assessment, care, and evacuation. The medic assumes primary responsibility for the team's operations after the team takes on a patient and takes charge when the team is working on a patient.

The medic is expected to be qualified at the level of "Emergency Medical Responder" (formerly known as First Responder) and is expected to be competent at basic trauma management, basic life support, and patient treatment and preparation for transport.

Co-Captain

The team co-captain is responsible for team communication to the FAB, as well as overseeing the action of the team as a backup for the captain. If the team captain becomes incapacitated, the co-captain assumes command of the team.

Fresh Air Base

Stationed at the FAB, the FAB team members are responsible for communicating with the team, maintaining simultaneous mapping with the team, acting as a communications link between the team and the Command Center, and acting in an oversight role, thinking ahead and planning.

Technician (Bench Person)

The team's technician or bench person is responsible for maintaining the operational readiness of the team's equipment and repairing damaged equipment as needed. He or she is expected to maintain competence in the specifics of the team's breathing apparatuses, gas detection equipment, communications system, and other complex items required for team use.

ELEMENTS OF TEAM OPERATIONS

Cooperation

It is important for each team member to cooperate with others on the team. Cooperation is what makes the team a functioning unit, rather than just a disorganized group. A team must be able to work together to adequately or effectively conduct operations.

Coordination

Coordination is another key element of team operations. It is important for each team member to coordinate what he or she is doing with what other members are doing. This may seem difficult at first because each team member has specific tasks, but at the same time all must work toward a common goal.

Communication

One must never forget the importance of good communication in mine rescue. Whether working with verbal or nonverbal commands or instructions, it is very important that they be received and interpreted properly. It is absolutely essential that everyone on the team knows what to do at all times. Listening and understanding are also important elements of communication, especially during a briefing. Each team member must learn to listen effectively so everything one needs to know can be understood the first time around. During an emergency, there may be no time to repeat instructions. If a team member listens carefully during a briefing and still does not understand something or if some information has been left out, he or she should not hesitate to ask questions. *During an actual emergency, a single missing fact could be crucial in determining how well the team functions. It could even mean the difference between life and death.*

Discipline

Discipline keeps the team members working together, and it establishes a set method for doing things so that *how* the team functions becomes second nature. The automatic, disciplined response of a well-trained team is especially beneficial during an emergency because it frees the members to concentrate on the work at hand. Mine rescue and recovery work involves a wide variety of tasks. The way the team responds will vary according to the type of mine emergency and the type of mine being entered. Conditions within the area the team plans to enter will also determine what the team will be required to do.

Some of the duties that may be required during an actual emergency are:

- Exploring the affected area of the mine
- Searching for and rescuing survivors
- Performing first aid
- Determining the extent of damage
- Determining gas conditions
- Mapping the team's findings
- Locating and fighting small fires
- Building temporary and/or permanent stoppings/bulkheads
- Erecting seals in a fire area
- Clearing debris, pumping water, and installing or erecting temporary roof supports
- Returning the mine to operating condition

TEAM MEMBER RESPONSIBILITIES

Responding

Members of a mine rescue team volunteer their participation as responders in the event of a mine rescue emergency and are expected to be prepared to respond per their organization's expectations. This preparation can be as simple as keeping a cell phone charged or the volume of a radio turned up enough to be heard at the mine, or it can be as complex as maintaining a "go-bag" in a responder's personal vehicle and carrying a pager.

Team members should be ready to respond for multiple days at a time to an extended-duration emergency and keep equipment assigned to them at a state of readiness. Adequate rest, and proper nutrition and hydration can make this process easier. Your group may have more specific requirements for team members as to how they are to be prepared and what equipment is to be ready.

Medical Standards

Team members are expected to meet or exceed the standards for mine rescue team members as specified by 30 CFR 49.7:

Physical requirements for mine rescue team.

(a) Each member of a mine rescue team shall be examined annually by a physician who shall certify that each person is physically fit to perform mine rescue and recovery work for prolonged periods under strenuous conditions. The first such physical examination shall be completed within 60 days prior to scheduled initial training. A team member requiring corrective eyeglasses will not be disqualified provided the eyeglasses can be worn securely within an approved facepiece.

(b) In determining whether a miner is physically capable of performing mine rescue duties, the physician shall take the following conditions into consideration:

  (1) Seizure disorder;

  (2) Perforated eardrum;

  (3) Hearing loss without a hearing aid greater than 40 decibels at 400, 1,000 and 2,000 Hz;

  (4) Repeated blood pressure (controlled or uncontrolled by medication) reading which exceeds 160 systolic, or 100 diastolic, or which is less than 105 systolic, or 60 diastolic;

  (5) Distant visual acuity (without glasses) less than 20/50 Snellen scale in one eye, and 20/70 in the other;

  (6) Heart disease;

  (7) Hernia;

(8) Absence of a limb or hand; or

(9) Any other condition which the examining physician determines is relevant to the question of whether the miner is fit for rescue team service;

(c) The operator shall have MSHA Form 5000-3 certifying medical fitness completed and signed by the examining physician for each member of a mine rescue team. These forms shall be kept on file at the mine rescue station for a period of one year.

Surface Operations and Incident Command

INCIDENT NOTIFICATION

Each mine must have an Emergency Notification Plan for notifying necessary personnel when there is an emergency at the mine. This plan lists the various supervisors, administrators, and government officials who must be notified in case of an emergency.

Federal regulations require mines to have and post a Mine Rescue Notification Plan for notifying all the mine rescue team members who will be needed to assist in the rescue and recovery operation (30 CFR 49.9).

The mine's notification plan should also include any other people or services that will be needed at the mine site such as law enforcement, supply clerks, telephone operators, ambulances, medical personnel, and/or other emergency responders.

Anytime team members are working or in the area they should be prepared to be called out in a rescue scenario. As stated previously, these individuals are responsible for a minimum contingent of personal gear as well as conditioning to respond.

SURFACE FACILITIES

Command Post/Command Center

The Incident Command Post (ICP) (or Command Center) is the hub of rescue and recovery operations and is typically staffed and controlled by a mine emergency "command staff." This group is generally composed of mine management personnel, federal and state officials, and union representatives, according to the site's Emergency Response Plan and the Incident Command System (ICS).

The Command Post makes all decisions concerning the mine rescue teams (scheduling, assignments, tracking, rotations, and methods of exploration or firefighting).

An incident has a single Command Post with a single incident commander who has final oversight and control over the entire incident.

Team Staging Area

The staging area is where teams wait for assignment or are held until it is time for their assignment to begin. The staging area can be part of a camp or rest area, may be close to the entry of the mine to minimize delays, or at the underground fresh air base (FAB) if immediate response is anticipated.

Team Quarters

The logistics section makes arrangements for food and sleeping quarters for all personnel at the mine. Usually food is brought in and rooms at a nearby motel are reserved. If there are no motels nearby, arrangements should be made for sleeping quarters at the mine itself. The ICS defines these areas as camps (if separate from incident site) or as part of the incident base.

Laboratory

If it is necessary to test samples of the mine air during the rescue and recovery operation, a laboratory with suitable air-analysis equipment should be set up at the mine for testing such air. If this is not possible, the air samples may have to be sent to an off-site laboratory for analysis. The Mine Safety and Health Administration (MSHA) owns and maintains several portable gas-testing laboratories for mine emergency use.

Bench Area

An area that has work benches where water is available should be set aside as an apparatus room where the apparatuses can be cleaned, tested, and prepared for use by the bench person or by the team members. This space should be of sufficient size to permit use by at least one team with basic equipment for washing, drying, and bench testing available.

Medical Facilities

The expected magnitude of the event will change the requirements for medical receiving, but some options for the team may include:

- **Ambulance standby/ground evacuation.** For smaller incidents, ambulances are staged near the portal for immediate hand-off from the team to the emergency medical services (EMS) system to facilitate immediate transport to a trauma receiving center.
- **Air evacuation.** For particularly remote or inaccessible sites, aeromedical evacuation (typically by helicopter) may be necessary. Teams should consult and familiarize

themselves with their local air-ambulance service's procedures for landing zones and helispots.

- **On-site triage and treatment.** For very large incidents, EMS agencies may choose to set up on-site triage and treatment for patients based on their mass-casualty/multiple-casualty incident (MCI) protocol. Patients would be sorted, treated or stabilized as possible, and evacuated by ground or air as needed.

In general, the local EMS agency should be consulted about how it would handle the incident and what it needs as far as support from the mine.

Press Briefing Area

Members of the media should be sent to a specific location for briefing and updates on the situation as the event progresses. This location should have sufficient parking for large vans and adequate aerial clearance. This site should be off the mine property entirely.

Family and Friends Waiting Area

The families and friends of miners who may be trapped should be sent to a specific waiting area for briefing, care, and comfort. They should be updated as soon as possible about any changes or rescued survivors. This area *must be completely isolated* from the Press areas and should be restricted to families and friends only.

Safety Zones

One of the earliest decisions the Incident Commander makes is the organization of the surface facilities. The Safety Officer or Incident Commander should lay out, at the very least, a schematic plan of the surface areas based on a set of three zones—hot zone, warm zone, and cold zone. See Figure 1 for a sample surface layout.

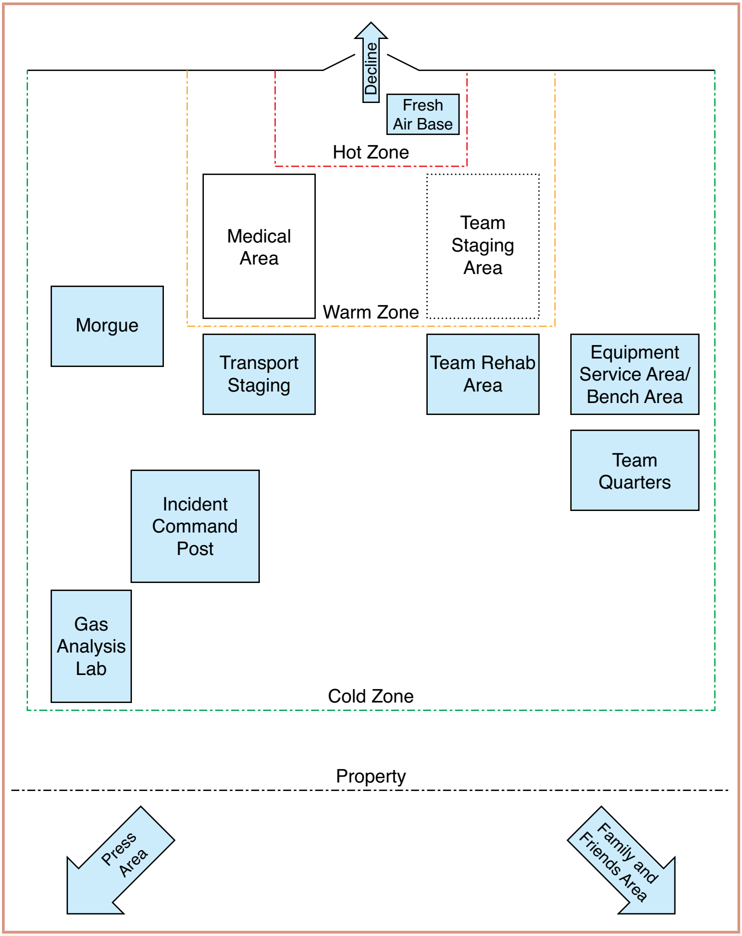


Figure 1 Sample surface layout

Hot Zone

The *hot zone* is the portion of the incident area actually affected by the event or that may be impacted very rapidly. Only essential personnel are to be in the hot zone, and they should have a full set of personal protective equipment (PPE) for the anticipated hazards. FAB is located within the hot zone. It should be as close to the incident as possible but assured of safe air and at relative safety from the incident itself.

Warm Zone

The *warm zone* is a transition location between the immediate hazard in the hot zone and the relative safety of the cold zone. This warm zone is where teams stage before entering the hot zone and where medical treatment is to happen. Personnel in the warm zone should have additional PPE from that needed for the cold zone, but they do not need the same protection as members underground. A bare minimum for personnel in this area would be eye protection, steel-toe boots, protective headgear, and long pants.

Cold Zone

The *cold zone* presents minimal danger to personnel, but access should be restricted to only those involved in the operation. The ICP, team rehab and equipment service areas, and transport staging areas would be in the cold zone. Personnel in this zone should comply with the basic PPE requirements of the mine as needed.

INCIDENT COMMAND SYSTEM

The ICS was created in the 1960s to coordinate and unify management of large wildfire incidents in the Western United States. The system was designed to be extremely flexible while maintaining a unified command and control for an incident. ICS was

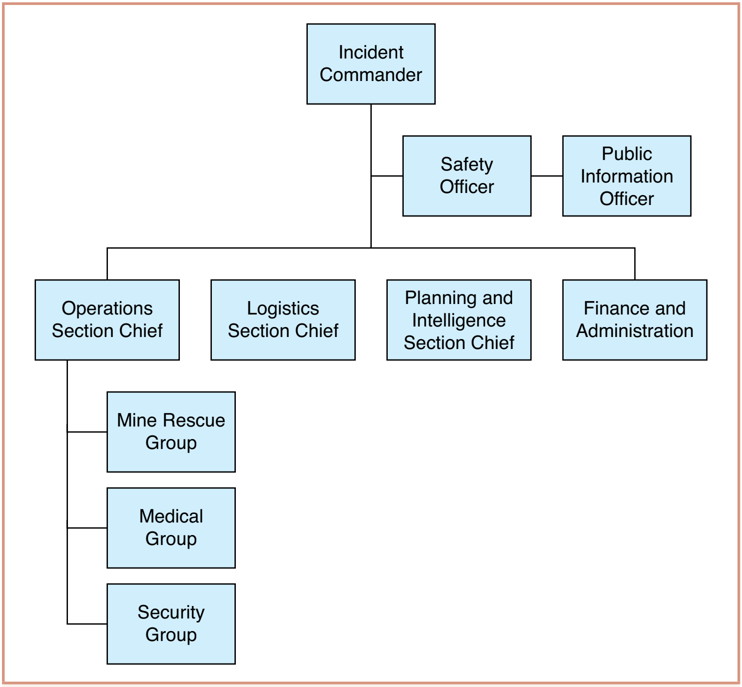


Figure 2 Incident Command System

standardized as part of the National Incident Management System (NIMS) and is required to be used by first responders for large incidents. The flowchart in Figure 2 shows the ICS hierarchy.

ICS was developed and implemented to remove certain key stumbling blocks that had been determined as weaknesses in incident management. These weaknesses included:

- Lack of accountability, including unclear chains of command and supervision
- Poor communication due to both inefficient uses of available communications systems and conflicting codes and terminology

- Lack of an orderly, systematic planning process
- No predefined methods to integrate interagency requirements into the management structure and planning process effectively
- Freelancing by individuals with specialized skills during an incident without coordination with other first responders
- Lack of knowledge of common terminology during an incident

Principles of the Incident Command System

Unity of Command

Each individual participating in the operation reports to only one supervisor. This eliminates the potential for individuals to receive conflicting orders from a variety of supervisors, thus increasing accountability, preventing freelancing, improving the flow of information, helping with the coordination of operational efforts, and enhancing operational safety. This concept is fundamental to the ICS chain-of-command structure.

Common Terminology

Previously, individual response agencies developed their protocols and terminology separately from each other. This situation can lead to confusion as a word may have a different meaning for each organization.

When different organizations are required to work together, the use of common terminology is an essential element in team cohesion and communications—both internally and with other organizations responding to the incident.

An ICS promotes the use of a common terminology and has an associated glossary of terms to help bring consistency to position titles, the description of resources and how they can be organized, the type and names of incident facilities, and a host of other subjects. The use of common terminology is most evident in the titles of command roles such as *Incident Commander, Safety Officer, or Operations Section Chief.*

Management by Objective

Incidents are managed by aiming toward specific objectives. Objectives are ranked by priority, should be as specific as possible, must be attainable, and, if possible, given a working time frame. Objectives are accomplished by first outlining strategies (general plans of action), then determining appropriate tactics (how the strategy will be executed) for the chosen strategy.

Flexible and Modular Organization

The Incident Command structure is organized so that it can expand and contract as needed by the incident scope, resources, and hazards. Command is established in a top-down fashion, with the most important and authoritative positions established first. For example, Incident Command is established by the first arriving unit.

Only positions that are required at the time should be established. In most cases, very few positions within the command structure will need to be activated. For example, a single fire truck at a dumpster fire will have the officer filling the role of Incident Commander (IC), with no other roles required. As more trucks are added to a larger incident, more roles will be delegated to other officers, and the IC role will probably be handed to a more-senior officer.

Only in the largest and most complex operations would the full ICS organization be staffed. Conversely, as an incident scales down, roles will be merged back up the command tree until just the IC role remains.

Span of Control

To limit the number of responsibilities and resources being managed by any individual, the ICS requires that any single person's span of control be between three and seven individuals with five being ideal. In other words, one manager should have no more than seven people working under him or her at any given time. If an individual is managing more than seven resources, then he or she is being overloaded and the command structure needs to be expanded by delegating responsibilities (e.g., by defining new sections, divisions, or task forces). If a person is managing less than three, then the manager on the next highest rung on the chain of command can probably absorb the position's authority.

INDIVIDUALS AND THEIR RESPONSIBILITIES

Incident Commander

- **Single Incident Commander**—Most incidents involve a single IC. In these events, a single person commands the incident response and is the final decision-making authority.
- **Unified command**—A unified command involves two or more individuals sharing the authority normally held by a single IC. Unified command is used on larger incidents, usually when multiple agencies or multiple jurisdictions are involved.

Command Staff

- **Safety Officer**—The Safety Officer (SO) monitors safety conditions and develops measures for ensuring the safety of all assigned personnel.
- **Public Information Officer**—The Public Information Officer (PIO or IO) serves as the conduit for information to and from internal and external stakeholders, including the media and/or other organizations seeking information directly from the area and/or those involved in the incident or event. Although it is less often discussed, the PIO is also responsible for ensuring that an incident's command staff is kept apprised as to what is being said or reported about an incident. This allows public questions to be addressed, rumors to be managed, and ensures that other such public relations issues are not overlooked.
- **Liaison Officer**—A Liaison Officer serves as the primary contact for supporting agencies assisting at an incident.

General Staff

- **Operations Section Chief**—The Operations Section Chief is tasked with directing all actions to meet the incident objectives. The Operations Section Chief oversees the mine rescue teams, on-scene security, medical operations and receiving, and other parts of accomplishing the team's goals.
- **Planning Section Chief**—The Planning Section Chief is tasked with the collection and display of incident information primarily consisting of the status of all resources and overall status of the incident. This role is best filled by a member of the technical or engineering staff who is familiar with the design, layout, and complexities of the mine as well as any specific hazards.

- **Finance/Administration Section Chief**—The Finance/Administration Section Chief is tasked with tracking incident-related costs, personnel records, requisitions, and administrating procurement contracts required by logistics.
- **Logistics Section Chief**—The Logistics Section Chief is tasked with providing all resources, services, and support required by the incident. The Logistics Section Chief typically fills the role of the supply clerk in older management models for mine rescue.

Other Roles

Mine Dispatcher—Duties of a Mine Dispatcher may include:

- Notifying all persons on the notification plan and informing them of the emergency
- Attending the telephone at the Command Center

Chief Electrician—Duties of the Chief Electrician may include:

- Opening and immediately locking out all electric switches to control all electrical services to the mine when instructed by the Incident Commander
- Providing materials for additional telephone communications as needed
- Arranging for any needed assistants

Chief Mechanic or Mechanical Foreman—Duties of the Chief Mechanic may include:

- Checking explosion doors (for exhausting fan) or weak wall (for blowing fan) for damage and ensuring repair
- Checking fan and, if necessary, instructing an electrician or machinist to make repairs to the fan

- Monitoring fan operation and the atmosphere in and around the fan house if the fan is exhausting (With an exhausting fan, proper precautions should be taken to avoid asphyxiation or an explosion in the fan house.)

Chief Engineer —Duties of the Chief Engineer may include:

- Providing copies of up-to-date maps showing the regular flow of air and the location of ventilation controls, doors, pumps, substations, all firefighting equipment, machinery, and the electrical system (with control switch locations)
- Alerting adjoining mines if they are connected underground with the affected mine
- Obtaining maps of adjoining mines
- Making arrangements to furnish drilling equipment, if needed

Equipment

Mine rescue teams are responsible for a set of specialized equipment necessary for any mine rescue operation. This equipment may include mining equipment or basic rescue supplies (see Table 2). The basic equipment for a team is specified in 30 CFR §49.6, and additional equipment may be added to suit the team's goals and intended operations.

Table 2 Individual equipment required for each team member

- Hard hat
- Cap lamp
- Safety glasses
- Work coveralls or other appropriate clothing
- ANSI-approved safety shoes
- Brass identification tag
- Any specific equipment for the position

LEGAL REQUIREMENTS

30 CFR §49.6 states the following:

(a) Each mine rescue station shall be provided with at least the following equipment:

(1) Twelve self-contained breathing apparatus, each with a minimum of 4 hours capacity (approved by MSHA and

NIOSH under 42 CFR Part 84, Subpart H), and any necessary equipment for testing such breathing apparatus;

(2) A portable supply of liquid air, liquid oxygen, pressurized oxygen, or oxygen generating chemicals, and carbon dioxide absorbent chemicals, applicable to the supplied breathing apparatus and sufficient to sustain each team for eight hours while using the breathing apparatus during rescue operations.

(3) Two extra, fully-charged oxygen bottles for every six self-contained breathing apparatus;

(4) One oxygen pump or a cascading system, compatible with the supplied breathing apparatus;

(5) Twelve permissible cap lamps and a charging rack;

(6) Four gas detectors appropriate for each type of gas that may be encountered at the mines served. Gas detectors must measure concentrations of methane from 0.0 percent to 100 percent of volume, oxygen from 0.0 percent to at least 20 percent of volume, and carbon monoxide from 0.0 parts per million to at least 9,999 parts per million.

(7) [Reserved].

(8) One portable mine rescue communication system (approved under part 23 of this title) or a sound-powered communication system.

  (i) The wires or cable to the communication system shall be of sufficient tensile strength to be used as a manual communication system.

  (ii) These communication systems shall be at least 1,000 feet in length.

(9) Necessary spare parts and tools for repairing the breathing apparatus and communication system.

(b) Mine rescue apparatus and equipment shall be maintained in a manner that will ensure readiness for immediate use.

(1) A person trained in the use and care of breathing apparatus shall inspect and test the apparatus at intervals not exceeding 30 days and shall certify by signature and date that the inspections and tests were done.

(2) When the inspection indicates that a corrective action is necessary, the corrective action shall be made and the person shall record the corrective action taken.

(3) The certification and the record of corrective action shall be maintained at the mine rescue station for a period of one year and made available on request to an authorized representative of the Secretary.

ADDITIONAL EQUIPMENT

The standard equipment required by law is not adequate for a full rescue operation, and more equipment may be necessary. Teams may decide what is or is not needed. The following list suggests additional equipment that a team may need for a rescue:

- Spare breathing apparatus
  - Patients to be extracted must be provided sufficient respiratory protection, and this apparatus also serves to provide oxygen therapy to inhibit shock.
- Two oxygen-generating self-contained self-rescuers (SCSRs)
- Team line
  - A 25-ft rope for team members to attach to in smoke
- Map board, pens, spare paper
- Scaling bar
- Current tester
- Breaching tools for doors

- Stretcher
- Backboard (long spine-immobilization board)
  - Straps for securing the patient
- Trauma bag
- Fire extinguishers
- Tool kit
  - Hammer
  - Saw
  - Nails
  - Crowbar
- Blankets
- Marking paint or chalk

PERSONAL PROTECTIVE EQUIPMENT

Each member of a mine rescue team is required to have breathing protection available any time there is a potential for the atmosphere to be contaminated or deficient in oxygen. MSHA requires that teams be equipped with 4-hour closed-circuit breathing apparatuses (CCBAs), and each team member wears one, with a spare on the stretcher. Team members should don their CCBAs at the first sign of hazardous atmospheric conditions and should only remove them once the team has guaranteed fresh air. See the procedure in Figure 3 for donning a breathing apparatus.

In the event of an apparatus failure:

1. **Immediately don the spare breathing apparatus or SCSR.**
2. **Evacuate the team to fresh air.**

Each team member should remain vigilant on the operating condition of his or her apparatus by monitoring the time remaining, the oxygen pressure remaining, and the rate that it is being depleted.

When donning breathing apparatuses, the team captain instructs the team:

1. **"Hard Hats Off."**

   Team members remove their hard hats and make sure that their masks are ready. The team captain makes sure that everyone is set before he or she proceeds.

2. **"Mask On, Chin In First."**

   Each team member puts on his or her mask, unconnected to the rest of the breathing apparatus, and makes sure that the mask is on correctly.

3. **"Chin Strap, Temple Strap, Top Strap."**

   Team members tighten each strap on the mask. Note: overtightening the top strap generally causes significant headaches while/after wearing an apparatus.

4. **"Connect Hose."**

   Team members connect the crosspiece of the apparatus hoses into the mask and ensure a proper fit.

5. **"Oxygen On, Waiting for Green Light."**

   Team members turn on the oxygen to their apparatuses and observe the gauge to ensure that the green "Ready for Use" light comes on, and they note the pressure in their cylinder.

6. **"Facemask Tightness Test, Breathe In, Breathe Out."**

   Team members crush their hoses on both sides to prevent air movement. They then breathe in and out to test whether the mask pulls in or pushes away from their face. If the mask moves correctly, it is on correctly and ready for use.

7. **"One-Second Bypass Press."**

   Team members press the bypass button, ensuring that the backup method to add oxygen functions and to add some additional oxygen to start the breathing cycle.

8. **Team Member Check**

   The team captain visually inspects each team member's:

   1. Facemask
   2. Straps
   3. Hoses
   4. Gauge
   5. Pack

   He or she then makes sure that each team member is OK to proceed, verbally asking each "Are you OK?" and verifies that they appear psychologically ready to begin work.

After these steps are completed, the team is ready to begin work wearing an apparatus.

Figure 3 Donning breathing apparatuses

If an individual is consuming abnormal amounts of oxygen or the oxygen is being depleted at an alarming rate, he or she should retreat to the surface and fix the apparatus. The team captain is ultimately responsible for maintaining vigilance over the whole team's breathing apparatuses.

Proper maintenance of the team's CCBAs is essential to team safety. The CCBAs must be carefully dismantled, cleaned, reassembled, and bench tested by a qualified technician every time the apparatus is used and must be kept in an operational state of readiness at any time the team is expected to be prepared to respond.

Teams may opt to have additional, shorter-duration (30 minutes to 1 hour) compressed air apparatuses that can be used for short operations where breathing protection is required briefly, such as firefighting in locations where atmospheres are safe. These apparatuses should not be used for principal mine rescue work and should not be treated as such.

CLOTHING

Proper clothing for mine rescue work varies substantially, depending on the intended activities of the team. Proper clothing should be sufficiently sturdy to handle the team's work, but comfortable enough to not hinder work or make the rescuer fatigued more rapidly. Clothing should also meet visibility standards at the mine and typically should incorporate reflective and high-visibility trim.

Flame-Resistant Coveralls/Uniforms

Flame-resistant clothing, compliant with National Fire Protection Association (NFPA) standards, is a typical choice for the operating uniforms for mine rescue teams. This clothing tends to be built to moderate-to-high durability and incorporates reflective trim for visibility, in addition to flame resistance. Many teams prefer flame resistance for the protection it affords in a flash fire, but does not have the same weight and bulk of full firefighting equipment.

Bunker Gear

Structural firefighting gear, better known as bunker gear, is designed for entry into the hazardous conditions of a structure fire. This gear can usually handle temperatures up to approximately 1,000°F and is built to be sufficiently durable for intense physical labor, abrasion, and heavy wear and tear. This durability comes by compromising the comfort of the user both with bulk and warmth. Bunker gear is generally only suitable at temperatures that would be hazardous to the team and where fire protection is essential. Teams should wear this kind of attire when they are specifically working to fight a fire or when they expect to encounter a fire of hazardous size.

Work Clothing (“Diggers”)

Work clothing provides limited to no protection against hazardous environments. However, it is substantially more comfortable and provides the freedom of movement needed to perform strenuous tasks or while doing work when minimum protection is required. Teams should be equipped at this level of protection when they do not expect to encounter fires or an explosion hazard and intend to do recovery work or other tasks with lower hazard.

Hard Hat/Helmet

Team members should wear head protection *at all times* on the scene of an accident or mine rescue emergency. Falling objects, flying objects, and other hazards exist. If properly marked, headwear can be helpful for visibility and team identification.

Teams have the option to choose what protective headwear is appropriate for their teams but at a bare minimum should be compliant with ANSI/ISEA (American National Standards Institute/International Safety Equipment Association) Standard Z89.1-2014 and at a level specified for "general helmets," just the same as hard hats for general industrial or mining use. This type of hard hat is sufficient for most mine rescue purposes but is not sufficient for firefighting or exposure to high temperatures. It also tends to lack a chin strap and can be inconvenient for work at height or on rope.

The next level of protective headwear includes fire helmets, technical rescue helmets, and search-and-rescue helmets. These are built to a higher standard than regular industrial helmets, can withstand greater impacts, are high-temperature resistant, and are designed to be worn in hazardous environments. These helmets are preferred any time a team is going to be exposed to a hazardous environment and are suitable for firefighting or exploration. Team members should ensure that these helmets comply with the relevant standards for the work they intend to do and meet the performance requirements as needed.

Helmets should be equipped with lighting for work, and these lights should be considered intrinsically safe for work in hazardous environments. They should be attached to the helmet well enough to ensure they are not lost. In addition, each team member needs to ensure that his or her light is focused as desired. Light-emitting diode (LED) light systems are the current state-of-the-art for personal lighting and have battery lives on the order of 12+ hours at maximum brightness.

Boots

Team members are also expected to wear protective shoes while conducting rescue operations. Like all the previous items of clothing, multiple levels of protection exist, but boots for mine rescue teams should exceed the basic standard for working at a mine site. Teams may go further with specialized or cross-rated boots designed for technical rescue, urban search and rescue, emergency medical services, or wildland firefighting, but this is based on the judgment of team leadership for potential situations the teams may encounter.

Exploration

Exploration and survey of the underground area is the only way for a mine rescue team to complete the search and rescue of survivors after a mine disaster.

BRIEFING AND RECONNAISSANCE

Before a team enters a mine, or begins work, the team is briefed by a command staff member, either the Operations Section Chief, Incident Commander, exiting team captain, or any combination of these individuals. The team is to be briefed on the status of the incident, its objectives, to whom team members report, and other goals and specific details about which the team needs to be informed.

The team should ensure it has the following information (at a minimum):

- Missing miners
  - How many miners are missing?
  - Has there been any contact with them?
  - Where were they working?
  - What are their skills and training levels?
  - What condition were they in?

  - Do any miners have pre-existing medical conditions (e.g., diabetes, asthma)?
- Cause of accident
  - What was the cause of and what details are known about conditions after the event?
- How much exploration has been completed
  - What has been found so far?
- Entrances
  - Have the entrances been examined? (What are the findings?)
- Ventilation system
  - Is it operating?
  - How does it function?
  - Have air samples been taken?
- Underground conditions
  - Are there gas emissions from rock?
    - Where?
    - What kind of gases?
  - Is there groundwater?
  - Is there geothermal activity (hazardously high heat)?
  - Is there unstable ground in specific regions?
    - What kind of ground support is used?
    - Where is bad ground often found?
  - Is there any atypical geology or rock?
- Mining operations
  - What method is used?
  - What kind of ore is in the mine?
  - How big are openings?
  - Are abandoned stopes sealed off?
  - What kind of equipment is used? Diesel or electric?
- Hazardous materials and conditions
  - Is there fuel, oil, solvent, or lubricant storage?
  - Are there shop areas?

  - Are there explosive magazines?
  - Is there oxyacetylene equipment?
- Utility status (on or off?)
  - Water?
  - Power?
  - Air?
  - Mine phones?
  - Radios?
  - Other digital communications?
- Are there any refuge chambers or places miners congregate?
- Is there any firefighting equipment underground?

Examination of Openings

Before a team proceeds underground, an examination of all openings should be undertaken or the team should be apprised regarding the current conditions of the openings. All mine openings should be guarded to prevent unauthorized entry to the mine and to provide personnel accountability for those entering/exiting. Based on a team's discoveries and conclusions from this information, the team and Incident Command can formulate an approach to affecting a rescue.

> **Information is a key commodity in an emergency, and the more information that Incident Command and the individual teams have, the more effectively they can function. The team functions as the eyes and ears of command.**

A proper examination of a mine entrance should result in the following data:

- Gas readings for all testable gases
- Air movement, quantity, and direction

- Presence of smoke
- Ground conditions (stability, support, etc.)
- Any other pertinent observations (seeing lights approaching, spotting running equipment in an entry decline, the successful operation of a cage, etc.)

PREPARING TO GO UNDERGROUND

Before a team goes underground, a few critical steps need to be taken to ensure the readiness of the team and the team's equipment. It is the captain's responsibility to ensure that the team members, their equipment, and their apparatuses are ready to go. The captain should:

1. Check each team member to ensure he or she is physically fit to wear the apparatus and to perform rescue work. Bushy sideburns and beards prevent a good face-to-facepiece seal, so all team members should be clean shaven.
2. Ensure that each team member's apparatus has been properly prepared and tested.
3. Ensure the team has all necessary tools and equipment (including the captain's own supplies, such as notebook, pencil, chalk, etc.).
4. Check the team's stretcher to ensure that all equipment is ready to function and has no notable defects (deflated tires, broken welds, missing straps, misaligned handles, supplies not secured properly, etc.).

Once the team arrives at the fresh air base (FAB), it is the captain's responsibility to make the final preparations and arrangements before the team proceeds further. The captain should:

1. Ensure that team members understand the briefing instructions and what their individual jobs will be.
2. Verify the gas-testing equipment, the communication equipment, signaling equipment, and that the stokes basket or stretcher have been checked by the designated people.
3. Establish what communications systems will be used with the FAB coordinator.
4. Synchronize watches with the FAB coordinator.
5. Get up-to-date information from either the previous team captain or the coordinator about how far the last team advanced and what was found.
6. Ensure that the team's map person gets an updated map from the last team's map person or from the FAB coordinator.

FRESH AIR BASE

The FAB is the base of operations from which rescue and recovery work advances into potentially unsafe atmospheres. This is where apparatus crews begin their exploration of the affected area.

The FAB also functions as a base of communications for the operation linking the team, the Command Center, and all support personnel.

Setup and Location Choice

Often, the operation's initial FAB will be established somewhere underground. In some mines, especially shaft mines, it may be necessary to establish the initial FAB on the surface. Sometimes the FAB will remain on the surface throughout the entire operation.

Regardless of whether the FAB is on the surface or underground, it must be located as close as possible to where the team is working and there must be a constant flow of fresh air at the site.

Underground, refuge chambers are sometimes used as FABs, or a FAB can be set up in a drift, entry (for single-level, room-and-pillar mines), or crosscut close to the affected area. *If there is any uncertainty about the potential contamination of the air at the FAB, an air lock must be built to isolate the FAB from the unexplored area beyond it. The air lock prevents mixing the atmospheres, and still permits team movement.*

When setting up the FAB, the following criteria are essential:

- Ensure the FAB is located where positive ventilation and adequate fresh air are continuously available.
- If the FAB is underground, it should be located where there is always an escapeway to the surface through fresh air. This travel way will be used to safely move people and supplies to and from the FAB. If possible, there should also be transportation available.
- The site should be situated where it can be linked to the Command Center by means of a communication system.
- There should also be a communication system to link the team and the FAB.
- The rock surrounding the FAB site must be structurally sound, and evaluated and supported as needed.

Beyond these basic criteria, the specifics are fairly flexible. The decision on the FAB is up to the Incident Commander, after considering the various logistical concerns associated with a stationary operating position.

Other factors to consider:

- Utility access
- Cleanliness
- Space for teams and other workers
- Working tables, chairs, and so forth
- Lighting, temperature control, and so on

Fresh Air Base Coordinator

Stationed at the FAB, there will be a person who is responsible for establishing and maintaining orderly operations. This is the FAB coordinator.

The FAB coordinator is responsible for coordinating all FAB activities and the activity of the team. This individual is responsible for managing communication between the team and the Incident Command Post and relaying the instructions of command.

The FAB coordinator's other primary activity is tracking the team's progress on the mine map while simultaneously mapping the team's findings. Coordinating and tracking the activity of the team ensures accountability for the team's work and that the backup team and Incident Command remain "on the same page" simultaneously.

Sometimes additional personnel are stationed at the FAB to carry messages from the FAB to the Command Center in the event of a communication breakdown. The runners may also be responsible for other tasks such as taking gas samples to the surface, monitoring the communication system cable, preparing apparatuses, or other work to ensure the continual operation of the team.

Advancing the Fresh Air Base

In single-level room-and-pillar mines, the FAB is usually advanced closer to the affected area of the mine as soon as areas forward of the base are explored and reventilated. This ensures that the apparatus crews will begin their explorations as close as possible to the affected area of the mine.

To advance the FAB, the team will have to build a new air lock at the site of the new FAB and put up any additional temporary bulkheads in parallel entries that are needed to seal off the area at that point so that fresh air can be advanced.

In addition, the team will have to repair any damaged ventilation controls in the area between the old FAB and the new one. However, the team needs to ensure it makes the necessary adjustments for directing air to an exhaust airway. This ensures that the area can be properly flushed out and ventilated. Next, the team returns to the old FAB and removes or opens that air lock and any bulkheads in parallel entries. This permits air to enter and flush out the area up to the new FAB.

Before everyone is moved up to the new FAB, a team should explore the area between the old and the new base. Using appropriate gas-testing devices, the team should check all dead ends, intersections, and high places in the area to make sure they are adequately ventilated.

CONDUCTING EXPLORATION

After the FAB has been established and is functioning, the team may then begin exploration. The team assignments and rotations are assigned based on the size of the mine, the complexity of the hazards, and the condition of the team with a team working underground for no longer than 2 hours.

Barefaced Exploration

In some disaster situations, conditions may make it possible to conduct an initial exploration without the use of a self-contained breathing apparatus (SCBA), so called *barefaced exploration*. Barefaced exploration is conducted with an apparatus on each team member's back without the mask or oxygen on. The apparatus must be bench tested and ready to be used if the team needs respiratory protection.

Barefaced exploration should be conducted only when the ventilation system is operating properly and frequent gas tests indicate that there is sufficient oxygen with no buildup of carbon monoxide or other dangerous gases. A backup crew with apparatus should be stationed outside the area and ready to go in immediately to rescue the others if necessary.

Barefaced exploration is used to quickly establish the extent of any damage in the area and to establish a new point for the apparatus teams to continue exploration. Locomotives, personnel carriers, and other vehicles can be used during barefaced exploration as long as there is no smoke and no evidence of explosive gases.

During barefaced exploration, the crew uses the mine's communication system to report its progress and findings to the surface while the backup team tracks the team in the event of a loss of communication or another disaster underground.

A team completing barefaced exploration should be prepared to halt exploration in the event of any hazard, such as oxygen deficiency, hazardous gas buildup, fires, smoke, collapsed ground, or anything else the team captain decides could be hazardous. The team captain is expected to take action before a threat to the team becomes hazardous, for example, ordering the team members to don breathing apparatuses when hazardous gases reach half the irrespirable limits.

Focusing a Search

It is highly recommended the team defines a set of objectives before searching. These objectives are typically defined by Incident Command, but the team members can define some of their goals and how they want to complete these objectives. Search goals are typically based on the probable locations of survivors, accident scenes, and fires.

Potential survivor locations:

- Refuge chambers
- Workshops
- Working faces that have been barricaded
- Offices
- Enclosed rooms or spaces that are easy to seal
- Crushers, ore dumping, or similar locations
- Batch plants, and so on

Potential accident scenes:

- Shops
- Working faces
- Stopes
- Development drifts
- Anywhere else where miners are working
- Inherently dangerous or unsafe areas
    - Places where accidents are more likely to have either a natural or human-made hazard
    - Natural
        - Poor ground conditions
        - Faults
        - Areas of large water movement
    - Human-made
        - Shafts

  - Mechanical areas
  - Shops

Potential fire locations:

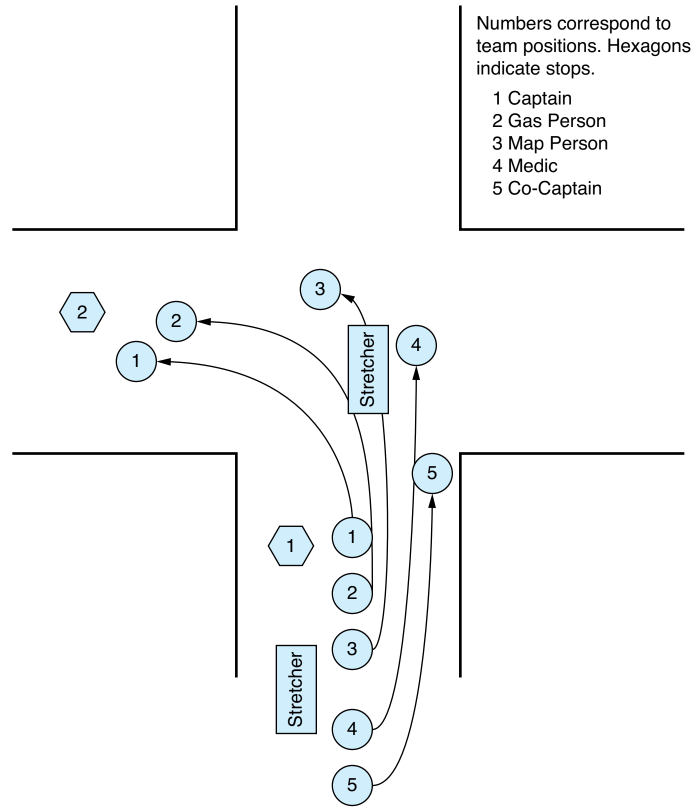
- Fuel storage areas
- Haulage routes
  - Declines
  - Spirals
  - Conveyor belt drive motors
- Explosives magazines
- Transformers and power centers
- Battery charging locations
- Workshops
- Any place where mobile diesel equipment tends to get collected in one place

Any of these locations would be worthwhile to search either for victims or for the cause of an accident. Team members must be very thorough when searching for survivors in areas where they may be hidden or buried, or when dense smoke restricts the team's visibility.

Systematic Exploration

Exploration should be conducted in a systematic manner as opposed to searching in a hasty or haphazard way. Conducting a search in a systematic manner prevents wasted time from covering territory twice and helps ensure team safety by keeping fresh air behind the exploring team. See the procedure in Figure 4 for working an intersection.

In general it is extremely dangerous to leave unexplored areas behind the team. It is more effective and more efficient for a team to tie across at intersections instead of proceeding straight in, allowing the team to explore all of the necessary areas while preventing the need for backtracking.

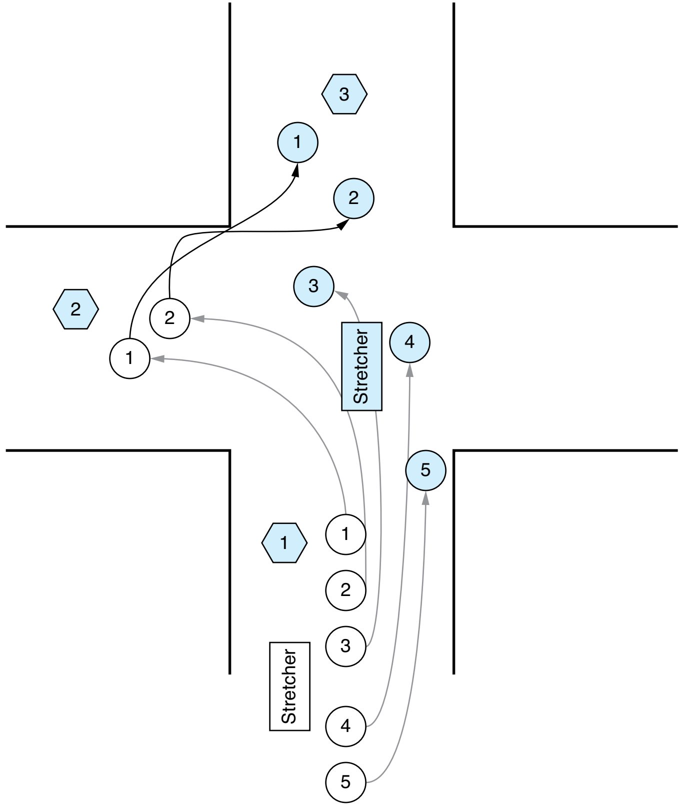


⟨1⟩ Team arrives at intersection.

⟨2⟩ Captain and gas person proceed to the left crosscut; captain checks ground and gas person checks gases. Map person moves to center of intersection, medic joins him or her, and co-captain moves to lower right corner.

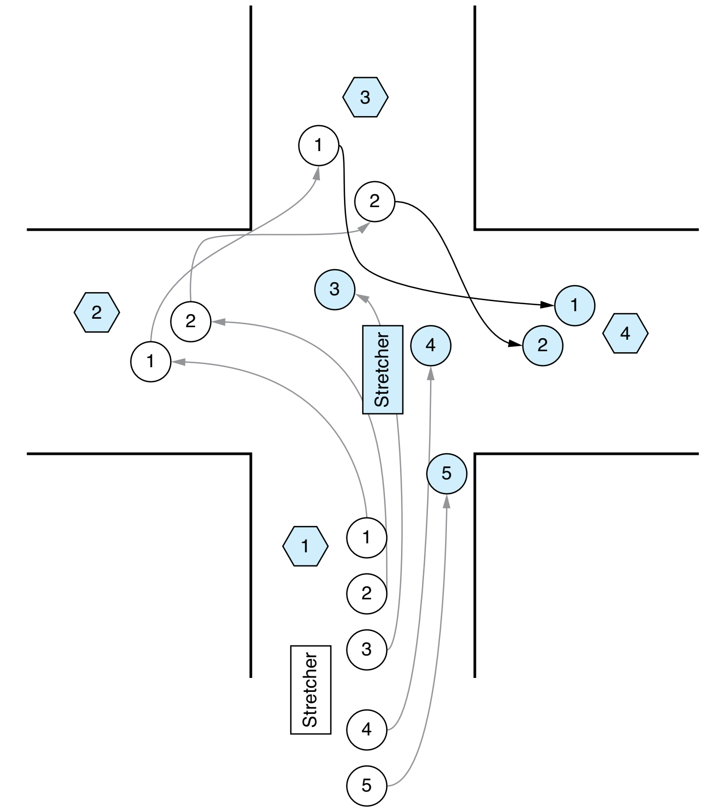
Captain and gas person proceed not more than 25 ft from the intersection if not on a tag line.

Figure 4 Working an intersection



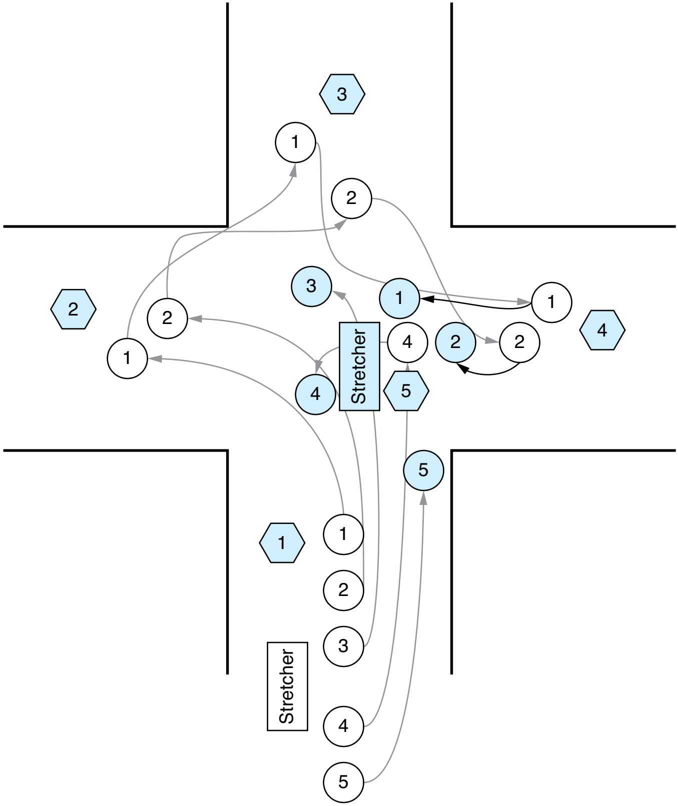
3 Captain and gas person move up to the center/forward direction from the intersection. Others remain stationary.

Figure 4 Working an intersection (continued)



4 Captain and gas person proceed to the right crosscut as others remain where they are.

Figure 4 Working an intersection (continued)



⟨5⟩ Team regroups around stretcher at center of intersection. Team then decides on course of action and requests permission to proceed.

Figure 4 Working an intersection (continued)

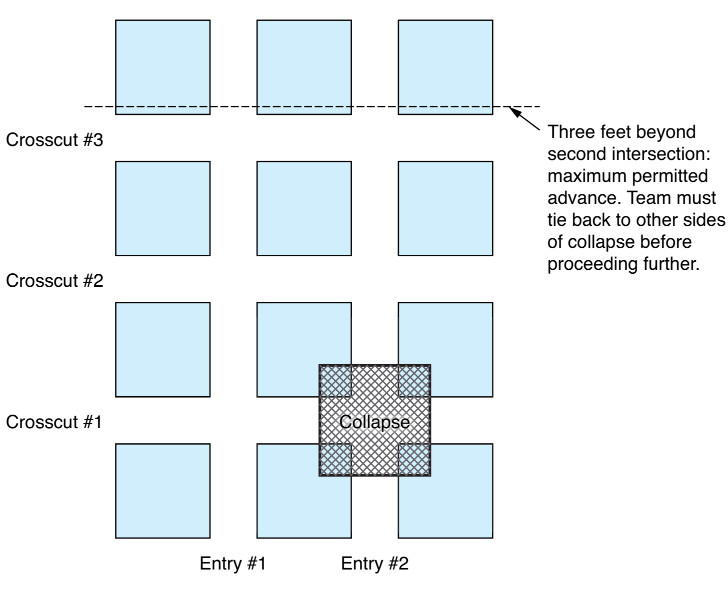


Figure 5 The 2+3 Principle

The 2+3 Principle

The 2+3 Principle is designed to help ensure that exploration proceeds systematically and to prevent a team from having its escape cut off by a fire or other progressing hazard (see Figure 5).

The 2+3 Principle (which refers to the second intersection plus 3 feet) states:

> *Where crosscuts are blocked, no team member may advance more than three (3) feet beyond the second (2nd) intersection before tying across. The second intersection will be determined by two crosscuts on either side of the entry being traveled. The first intersection will be the blocked intersection.*

Keep in mind that following the 2+3 Principle is strongly recommended but not absolutely required in a mine rescue operation. When in doubt, consult Incident Command for how it would prefer the team to proceed.

Route Choice

The route for the team to explore should be chosen deliberately. Often, this is dictated by the Command Center, but can be left to the team. When choosing a route to follow, the following factors should be considered:

- Escapeways and major haulage routes
  - Potential survivor locations, potential fire locations, fresh-air movement
- Ease of travel for team or potential survivors
  - Avoid ladders, climbing, and other physically demanding routes if possible. Energy should be conserved on a 2-hour assignment.
- Potential obstructions
- Certainty of escape route
  - Ensure safe passage for your team and a patient to exit the mine.
  - Remove any obstacles as you progress.

Searching in Open Air

Teams are expected to be complete and thorough in their searches. In general teams should be:

- Searching for survivors
- Checking ground conditions
- Checking gas conditions
- Looking for fires or other hazards
- Examining clues and other evidence

- Documenting other findings, equipment locations, supply caches, and anything that could help the team or investigators

The team typically progresses in a line, captain first, co-captain last; the team decides the order of the other three team members in between.

Searching in Smoke

Smoke exploration follows the same basic objectives as exploration through clear air with a few additional precautions. When smoke is encountered, the team should:

1. Count off, ensuring the entire team is present.
2. Connect to the 25-ft team line.
3. Assume the appropriate formation based on conditions.
   - Team members on edge keep one hand on the rib (wall) at all times.
4. Advance forward through smoke.
   - Search the floor for rubble, victims, clues, or other information.
5. Continue advancing until the team line tightens.
   - Line tightens as the first and fifth get 25-ft away from each other, typically at an intersection.
6. Pick direction to travel and continue.

If smoke becomes too thick and a light is giving too much glare, it can be removed from the hard hat and allowed to dangle near the floor. Smoke tends to be thinner lower to the ground, and this could allow one to see something critical (a note in a lunch pail, a downed miner, a shaft, etc.).

Spatial disorientation, losing one's sense of direction, or becoming turned around is quite common during rescue exploration in

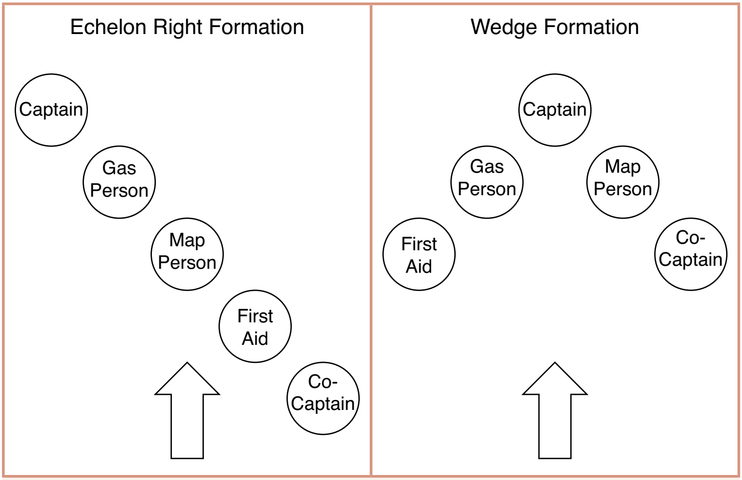


Figure 6 Team formations

smoke. This is prevented by being attached to the team line and by having the team members on the edges keep a hand on the rib at all times. If the farthest right team member (co-captain) keeps his or her right hand on the right rib, the team will not get turned around.

Team Formations

When exploring in smoke or water, it is recommended that teams take a different formation than simply a line down the center of a drift. These two options, as shown in Figure 6, provide the team complete coverage of the drift as they advance and help ensure that they keep a hand on the rib the entire time.

Both formations are acceptable for a team to use, and the echelon formation can be an echelon left if so desired by the team. In either formation, at least one team member keeps a hand on the rib at all times.

Ground Conditions

> **Teams should not enter water higher than knee deep.**

In smoke, ground conditions cannot be checked the traditional way. Scaling can result in either sparking or the downing of rocks, either of which may complicate the situation. Sparks may ignite explosive mixtures of gas within smoke or drop onto flammable materials igniting a fire. Falling rocks may fall onto a patient who was otherwise uninjured but was not noticed by the team.

Rubble on the ground is the best indicator of unsafe ground conditions when scaling is impossible. Ground that is loose enough to drop rubble is unsafe, and should not be proceeded under without proper supporting actions being taken. See "Ground Control" section.

Searching Water

Water exploration is very similar to smoke exploration with the team counting off, going onto the team line, and proceeding in a wedge or echelon formation. However, several precautions must be taken in water. The team must:

- Check the water for electrical current
  - Look for downed electrical lines as you approach and as you progress
- Stir with a scaling bar then check for gases above
  - Many mine gases are water soluble. See "Gases and Ventilation" section.
- Probe and search (dredge) the floor as you traverse
- Watch for:
  - Bodies
  - Steep drop-offs or holes
  - Rubble
  - Uneven footing

Water can obscure many hazards, so it is critical that teams remain alert when exploring in water. Holes that are obscured can potentially be hundreds of feet deep in abandoned or multilevel mines, and uneven footing can fail or make team members lose their balance.

MAPPING

As the team advances and explores, a major goal of the team is mapping and documenting the conditions underground. Mapping is essential to the team in order to maintain a record of existing hazards and to the Command Center and investigators to gain a better understanding of the overall incident.

As the team maps, it relays the information (findings and locations) back to the FAB in a process known as *simultaneous mapping*. This method keeps the FAB (and therefore command) fully informed of the situation underground and allows command to make decisions without waiting for the original map from the team. The following things should be mapped:

- Bad ground conditions
- Water
- Smoke
- Gas readings
- Valves on water and compressed air lines (open or closed)
- Firefighting equipment
- Other equipment and tools
- Types and position of powered equipment (on or off)
- Storage areas for materials
- Evidence of fire and/or explosion
- Dinner buckets and other signs of miners
- Condition of ventilation controls, air doors, main fans, booster fans, ventilation tubing, barricades, etc.

- Survivors
- Bodies
- Any other significant conditions, materials, and so on

The correct usage of mine map symbols is critical to ensure that the team's map is readable by others at a later date. Any potential sources of confusion should be clarified on the map itself where the condition is explicitly indicated. The Mine Safety and Health Administration's (MSHA's) uniform mine map symbols are described in detail in Figure 7.

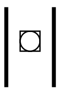
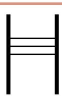
GT Gas Test	For each gas test conducted.
 Gas Reading	A gas or a mix of gases in the mine atmosphere. Write out the gas name or symbol and indicate ppm or %.
50 50-Foot Team Check	Used for 50-ft check of team members.
20 20-Minute Team Check	Used for every 20-minute apparatus check of team members.
 Seal	If the seal is equipped with devices such as sampling tubes or water traps, or is damaged, leaking, or destroyed, that particular device or condition is noted beside the symbol.

Figure 7 Uniform mine map symbols

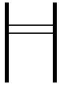
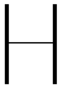
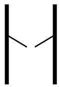
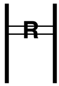
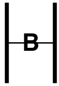
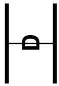
 Permanent Stopping, Intact	Stopping is intact, airtight. (No indication of opening or leakage.)
 Permanent Stopping, Not Intact	Stopping may be destroyed, partially destroyed, or have openings. It is not airtight. Condition noted on map beside symbol.
 Temporary Stopping, Intact	Stopping is intact and airtight. This symbol is used for all structures built by the team, such as air locks, and so on.
 Temporary Stopping, Not Intact	Stopping may be destroyed, partially destroyed, or have openings. It is not airtight. Condition noted on map beside symbol.
 Regulator	If the regulator is damaged, leaking, or destroyed, condition must be shown on map. Also, indicate whether open (how much) or closed.
 Barricade	Any information, such as leaking, damaged, destroyed, and so on, shall be noted on mine map beside symbol.
 Door	The "D" symbol can be shown by itself, in permanent or temporary stopping. Type, size, and open must be indicated on map beside symbol. The curve of the "D" indicates direction of door opening.

Figure 7 Uniform mine map symbols (continued)

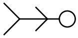
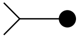
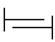
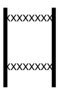
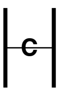
 Live Victim	Indicate position of head and feet as found. Write out condition, such as conscious, walking, and so on. Indicate any injuries; write out information on map beside symbol.
 Deceased Victim	Indicate position of head and feet as body is found. If word “body” is on placard, show symbol. Indicate any additional information on map beside symbol.
DI Date and Initial	Use for all locations where the team captain dated and wrote his or her initials.
PC Power Center	Make additional notes on condition as necessary.
BC Brattice Cloth Materials	Indicate any information on mine map beside symbol.
 Brattice Frames	Indicate any information on mine map beside symbol.
 Caved	Caved areas are not considered airtight unless established as such. Write out any information beside symbol on map.
 Check Curtain	Condition of check, must be shown on mine map beside symbol, for example, “Partially down.”

Figure 7 Uniform mine map symbols (continued)

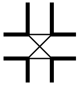
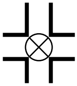
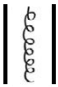
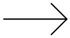
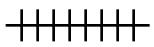
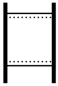
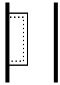
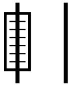
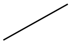
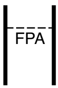
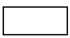
 Overcast	If it is damaged, leaking, or destroyed, that particular condition is to be noted on the map beside the symbol.
 Undercast	If it is damaged, leaking, or destroyed, that particular condition is to be noted on the map beside the symbol.
 Smoke	Write out light, heavy, dense, or any other information on map beside the symbol.
 Fire	Write out any information about fire on map beside symbol.
 Fan	Write out the conditions of the fan and any other information of note on the map beside the symbol.
 Fan with Tubing	Write out the conditions of the fan, tubing, and vent bag on the map by symbol.
 Air Movement	Show arrow in direction of movement and any quantity, if given, or other information, such as flow velocity. Put on map beside symbol.
 Track	Note any additional information on map beside symbol.
 Unsafe Roof Rib to Rib	Symbol used for any indication of questionable roof conditions. May or may not be scalable. Write out any other information on map beside symbol.

Figure 7 Uniform mine map symbols (continued)

 Unsafe Roof Partially Across	Symbol used for any indication of questionable roof conditions. May or may not be scalable. Write out any other information on map beside symbol.
 Unsafe Rib	Symbol used for any indication of questionable rib conditions. May or may not be scalable. Project over rib line area on map. Write out any other information on map beside symbol.
 Elongated Object	For use in indicating pipelines, cables, and other objects usually found that are of any length. Do not use for cable coiled, and so on. Write out any other information about object on map beside symbol.
 Furthest Point of Advance	Should be used only where areas inby will not be explored for whatever reason. Not to be used where other conditions block travel.
 Mobile Equipment	Use for all mobile equipment. Write out any other information given on map beside symbol on map.
 Water	Indicate depth or any other information. Put on map beside symbol.
 Other Information	Write the name of the object, condition, or equipment and other information indicated on map beside the symbol. This would include a “face.”

Courtesy of Mine Safety and Health Administration.

Figure 7 Uniform mine map symbols (continued)

MARKING PROGRESS

As the team advances, the captain marks areas explored by initialing and marking the date on crosscuts, impassable falls, barricades, bulkheads, air doors, and at other points where conditions do not permit the team to advance. All of these places should also be noted on the map. Marking areas as the team explores provides a visual record of what the team did and found as it advanced. Two notable styles exist: one developed and used by urban search and rescue (USAR) teams and one originating in mine rescue. A team has the option to determine the method it uses to mark its route and its progress based on the preferences, trainings, and specializations of the team.

USAR Style

USAR teams have developed a system of marking progress, building assessment, and patient location (see Figure 8). This system is used extensively within the emergency services realm by professional and volunteer teams in the United States.

Structure and Hazards Marking

- A 2 ft × 2 ft square box is outlined at any entrance accessible for entry into any compromised structure.
- Aerosol cans of spray paint (International Orange color only) will be used for this marking system.
- It is important that an effort is made to mark all normal entry points to a building or mine area under evaluation to ensure that personnel approaching the building can identify that it has been evaluated and discern its condition.
- Specific markings will be clearly made inside the box to indicate the condition of the structure and any hazards at the time of the assessment.

- Normally the square box marking would be made immediately adjacent to the entry point identified as safe. An arrow will be placed next to the box indicating the direction of the safe entrance if the Structure and Hazards marking must be made somewhat remote from the safe entrance.
- The time, date, and team captain identification (ID) will also be noted outside the box at the upper right-hand side. This information will be made with pieces of carpenter's chalk or lumber crayon.

	Area is accessible and safe for search and rescue operations. Damage is minor with little danger of further collapse.
	Area is significantly damaged. Some areas are relatively safe, but other areas may need shoring, bracing, or removal of falling and collapse hazards.
	Area is not safe for search and rescue operations and may be subject to sudden additional collapse. Remote search operations may proceed at significant risk. If rescue operations are undertaken, safe-haven areas and rapid evacuation routes should be created.
	Arrow located next to a marking box indicates the direction of safe entrance to the area, should the marking box need to be made remote from the indicated entrance.
HM	Indicates that a HAZMAT condition exists in or adjacent to the structure. Personnel may be in jeopardy. Consideration for operations should be made in conjunction with the Hazardous Materials Specialist. Type of hazard may also be noted.

Courtesy of the Federal Emergency Management Agency.

Figure 8 Structure and hazard marking (USAR style)

Courtesy of the Federal Emergency Management Agency.

Figure 9 Sample marking

The time, date, and team are noted outside the box at the upper right-hand side. This information is made with carpenter's chalk or lumber crayon. An optional method is to apply duct tape on the exterior of the structure and write the information with a grease pencil or black marker.

The example in Figure 9 indicates that a safe point of entry exists above the marking (possibly a window, upper floor, etc.). The single slash means the structure may require some shoring and bracing. The assessment was made on July 15, 1991, at 1:10 PM. There is an apparent indication of natural gas in the structure. The evaluation was made by Task Force #1 out of the State of California.

As each subsequent assessment is performed throughout the course of the mission:

- A new time, date, and team name entry will be made below the previous entry, and
- A completely new marking box will be made if the original information is now incorrect.

Marking boxes are also placed in each of the specific areas within the structure (rooms, hallways, stairwells, etc.) to denote conditions in separate parts of the building.

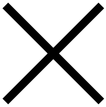
Search Assessment Marking

When a team searches an area, different markings are used to show the search progress, as well as the completion of a search. The team also notes what was found in the area, clearly indicating these findings for other arriving teams:

- A separate and distinct marking system is necessary to conspicuously denote information relating the victim location determinations in the areas searched.
- The Search Assessment marking system is designed to be used in conjunction with the Structure and Hazards Evaluation marking system.
- An "X" that is 2 ft × 2 ft in size will be made with International Orange color spray paint. This X will be constructed in two operations (see Figures 10 and 11).
- Distinct markings will be made inside the four quadrants of the X to clearly denote the search status and findings at the time of this assessment.
- The marks will be made with carpenter's chalk, lumber crayon, or duct tape and black permanent marker.
- It is important that markings are made specific to each area of entry or separate part of the building.
- If no victims are found, it is noted with a "0" below the X.
- Situation updates are noted as they are available.
  - Previous search markings are crossed out.
  - New markings are placed below (or next to) their previous markings with the most recent information.

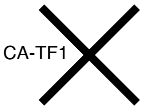
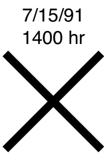
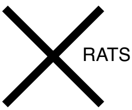
MSHA Mine Rescue Style

The captain or co-captain marks an arrow on the side at each intersection where the team's direction of travel changes. The head of this arrow points toward the FAB. As the team returns to the FAB, the captain or co-captain draws an X through each arrow to show

	Single slash drawn upon entry to a structure or area indicates search operations are currently in progress. The time and TF identifier are posted as indicated.
	Crossing slash drawn upon personnel exit from the structure or area.

Courtesy of the Federal Emergency Management Agency.

Figure 10 Construction of “X”

	LEFT QUADRANT – Team identifier
	TOP QUADRANT – Time and date that personnel left the structure.
	RIGHT QUADRANT – Personal hazards.
	BOTTOM QUADRANT – Number of live and dead victims still inside the structure [“0” = no victims].

Courtesy of the Federal Emergency Management Agency.

Figure 11 Sample distinct quadrant markings

that the team has retreated (see Figure 4). This method is designed to help in two ways:

1. Provides a visual indication of the escape route for the rescue team retreating to the FAB
2. Provides a trace to the backup teams on what way the team had travelled

The captain also marks his or her initials as well as the date and time at all locations where the team has stopped exploration and at the furthest point of advance. The marking may be done with chalk, marking spray paint, or other prominent, well-identifying marks.

The authors advise the usage of the USAR system to mark progress and assessment. This method is better recognized by other agencies and helps ensure interoperability and can be used with more than just underground searching.

TEAM CHECKS

A standard procedure during an exploration is the "team check." Team checks are conducted to:

- Ensure each team member is fit and ready to continue
- Ensure each team member's apparatus is functioning properly
- Give the team a chance to rest

Usually, the captain conducts the team checks by halting the team briefly, asking each team member how he or she feels, and checking each apparatus. It is recommended that team checks be conducted every 15 to 20 minutes. Under certain conditions, the team may not be able (or may not find it feasible) to stop this often.

It is also recommended that the first team check occurs as soon as possible after leaving the FAB. This first check is to ensure that no team member is feeling unfit to travel or an apparatus is malfunctioning. The journey back to the FAB is relatively quick and easy at this point, and potential exposure to hazardous atmospheres is limited.

The captain notes each team member's gauge reading at each rest stop and then reports the lowest reading to the FAB. The lowest reading may then be used as a reference point to determine when the team should return to the FAB.

In addition to checking each team member and apparatus, these stops allow the team to rest. If a team is searching for survivors, exploration should be conducted without undue delay. How long a team stops for each check will be determined by the conditions encountered and the work being done.

SUMMARY

Exploration requires that teams understand and are able to do the following:

- Form a plan
- Focus the search
- Scout entrances
- Establish a FAB
- Systematically explore and choose the route
- Search, with and without smoke
- Search water
- Rescue survivors
  - Open air
  - Behind barricades
- Evacuate patients

Team Goals:

1. Assess situation and determine course of action.
2. Begin search systematically.
3. Rescue survivors, based on criticality and location.
4. Extinguish any fires without undue delay.
5. Explore entire mine.
6. Return mine to working order per instructions of Incident Command.

Firefighting

Fires in underground mines are particularly hazardous not only because they produce toxic gases and heat but because they produce smoke, pose an explosion hazard, and create oxygen-deficient atmospheres.

CLASSIFICATION OF FIRES

Fires are broken down into a series of classes, each reacting in its own way to firefighting techniques. Adequate knowledge of these different types of fires and how they behave is essential to safely fighting a fire. The National Fire Protection Association (NFPA) classifies fire into the following four classes:

Class A — Fires involve ordinary combustible materials such as wood, plastics, paper, and cloth. Class A fires are best extinguished by cooling with water or by blanketing with certain dry chemicals.

*Think of Class A fires as those that leave **A**shes.*

Class B — Fires involve flammable or combustible liquids such as gasoline, diesel fuel, kerosene, and grease.

Typical Class B fires can occur where flammable liquids are spilled or leaked out of mechanical equipment. They are best extinguished by excluding air or by special chemicals that affect the burning reactions.

*Think of Class B fires as those that involve contents that will **B**oil.*

Class C — Fires are electrical fires. Typical Class C fires include electric motors, trolley wire, battery equipment, battery-charging stations, transformers, and circuit breakers. They are best extinguished by non-conducting agents such as carbon dioxide and certain dry chemicals. If the power has been cut off to the burning equipment, the fire can be treated as a Class A or B fire.

*Think of Class C fires as those that involve **C**urrent.*

Class D — Fires involve combustible metals such as magnesium, titanium, zirconium, sodium, and potassium. Special techniques and extinguishers have been developed to put out these fires because normal extinguishers generally should not be used on a Class D fire and could make the fire worse. Class D fires are not frequently found in mines.

*Think of Class D fires as those that go "**D**ing."*

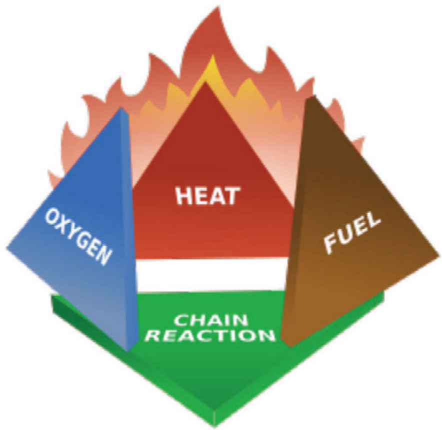


Figure 12 **Four parts of the fire tetrahedron**

FIREFIGHTING EQUIPMENT

Dry Chemical Extinguishers

Dry chemical extinguishers contain a powder-based agent that extinguishes by separating the four parts of the fire tetrahedron (see Figure 12). It prevents the chemical reactions involving heat, fuel, and oxygen, and halts the production of fire sustaining "free radicals," thus extinguishing the fire.

Two basic sizes of dry chemical extinguishers are handheld and larger wheeled extinguishers. Handheld extinguishers can range in size from 2 to 55 pounds, whereas wheeled extinguishers can be 75 to 350 pounds.

It is generally recommended that mine rescue teams use multipurpose dry chemical extinguishers, which contain monoammonium phosphate, because they are effective on Class A, B, and C fires.

Water

Water acts to cool the fire, removing heat from the fire tetrahedron, and is effective against Class A fires. In many mines, the water to fight fires underground can be supplied via water pipes, hand lines, fire engines, and fire cars.

Foam Generators

High-expansion foam is made by mixing water, air, and a foam concentrate or detergent in a foam generator. Many different models are available, varying in size and foam-producing capacities. They can be handheld or wheeled, and water-, electric-, or diesel-powered.

High-expansion foam is used to contain and control a fire by removing oxygen and heat. The volume of the foam smothers and cools the fire simultaneously. High-expansion foam can only be used for fighting Class A and B fires.

FIREFIGHTING PROCEDURES

An underground mine fire, if not extinguished quickly, can develop rapidly, create a serious hazard, and cause loss of life and property. The problem of controlling a fire increases in direct relationship to the time necessary to initiate control measures; basically, as a fire increases in size and intensity, it becomes progressively more difficult to cope with roof control, visibility, ventilation, and explosion prevention. Useful procedures helpful for extinguishing small fires and supported by successful research are listed in the bibliography of this manual. The publication *Mine Fires* by Donald W. Mitchell (1996) is particularly relevant to mine rescue teams. Remember, mine rescue teams are not equipped to extinguish large fires. These fires should be left to trained, well-equipped firefighters under the direction of the Incident Command Post (ICP).

When a team goes into a mine to fight a fire, team members should be concerned with the spreading of the fire and the possibility of an explosion. Before going underground, the team should ensure that all the standard underground exploration procedures are followed and the team is adequately prepared in terms of equipment and supplies to address the fire if it is found. The team should also be briefed on the location and condition of all firefighting equipment by the planning and intelligence section.

Before Going Underground

Before going underground, the team should know about:

- Possible ignition sources that may exist (i.e., battery-operated or diesel equipment)
- Underground storage areas for explosives, oil/grease, and oxygen or acetylene cylinders
- If there is electrical power to the affected area

Locating Fires and Assessing Conditions

Locating fires and assessing the conditions in and around the fire area is an objective of exploration work during a mine fire. The ICP will want to know as much as possible about the fire: where it is, what is burning, how large it is, and conditions near the fire area.

The teams can roughly determine where an unknown fire is and assess the size by reporting smoke conditions and feeling bulkheads for heat. If a small fire is encountered, the team should be able to extinguish it immediately. Large fires, however, may require more equipment and careful planning with the ICP to determine how to proceed based on the information gathered by the team.

DIRECT FIREFIGHTING

Direct firefighting means that an extinguishing agent is put directly onto the fire to extinguish it. This usually means the firefighters will have to get close to the fire in order to use the fire extinguishers, water, or foam. The fire should be approached from the intake air side, if possible, so the smoke and heat will be directed away from the team. If a team intends to engage in direct firefighting, team members should be wearing NFPA- and National Institute for Occupational Safety and Health (NIOSH)-approved firefighting clothing (bunker gear), and self-contained breathing apparatuses (SCBAs) approved for firefighting should be available at the fresh air base (FAB) along with extra air bottles.

If the fire starts to back up against the intake in search of oxygen, a "transverse" brattice can be put up with an open space at the top. This will cause increased airflow at the back and should slow down the progress of smoke and flame into intake air. Do not run the brattice too high, or it will cut off airflow and could result in an explosion.

Hazards of Direct Firefighting

Electric Shock and Electrocution

Electricity is a hazard to firefighters using water, foam, or other conductive agents to fight a fire. To avoid this, it is usually recommended that the power be cut off, regardless of the type of fire. This is done to avoid the electrical hazard and to cut power to electrical components that may be involved in the fire.

Toxic and Asphyxiating Gases

Carbon monoxide is extremely toxic and produced by nearly all fires because of incomplete combustion. Carbon dioxide, an asphyxiant, is produced as a product of complete combustion,

> **The fan should never be stopped or reversed while the team is underground.**

> **If any explosive concentrations of gas are detected in the exhaust air of the fire, the team should exit the mine immediately.**

and breathing large quantities of it causes rapid breathing and an insufficient intake of oxygen. Too much will cause unconsciousness and possibly death. Hydrogen sulfide may also be produced and is even more toxic than carbon monoxide. Other toxic gases, such as phosgene, can be produced from burning rubber, neoprene, or PVC (polyvinyl chloride). Because of the dangers of these gases, it is extremely important to wear a breathing apparatus at all times when dealing with underground fires.

Oxygen Deficiency

Because fires consume large amounts of oxygen, there is a hazard of oxygen deficiency in a mine. This provides another reason team members should always wear a breathing apparatus around underground fires.

Explosive Gases

It is important to maintain a sufficient and consistent flow of air over the fire area to avoid a buildup of explosive gases, such as hydrogen and methane. Small hydrogen pops are common in firefighting, and the bigger hazard is the possibility of the gas accumulating to a large enough extent to cause a violent explosion.

Heat, Smoke, and Steam

Smoke limits visibility and can cause disorientation, which may diminish a sense of balance and depth perception. Working in a hot or steamy atmosphere tends to make team members more exhausted than normal and cause additional stress to the team. The heat will also weaken the roof in the fire area, so the area should be checked and scaled frequently. Cold water applied to the hot rock may cause explosive fragmentation of the rock.

Methods of Direct Firefighting

Water

A water-based attack on a fire is the most common method of direct firefighting in mining and in the fire service. The team approaches the fire from the intake side, applying a fog of water on the approach, and then applies an aerated stream of water to the burning materials. This cools the fire, prevents oxygen inflow, and can inhibit continued reaction.

Portable Fire Extinguishers

Portable fire extinguishers are used as a rapid intervention technique to stopping a fire in the incipient stages. The mnemonic “PASS” is very helpful for correct use of an extinguisher:

Additional training in firefighting is essential to adequately fight a fire directly.

Pull	Pull the safety pin from the handle/lever.
Aim	Aim the nozzle at the base of the flames (burning materials).
Squeeze	Squeeze the handle, releasing the extinguishing agent at the base of the fire.
Sweep	Sweep side-to-side at the burning materials until the extinguisher is exhausted.

Be prepared to back off the fire if it flares up or to get another extinguisher if needed.

INDIRECT FIREFIGHTING

Sometimes direct firefighting is ineffective or not possible because of certain hazards such as high temperatures, bad ground, and explosive gases. In these cases, it may be necessary to fight the fire from a distance (indirectly) by sealing the fire or by filling the fire area with foam, sandfill, or water. This method works by excluding oxygen from the fire. The foam or water also serves to cool the fire. Carbon dioxide and nitrogen are also used to reduce the oxygen level in the underground openings to extinguish the fire.

Out-of-Control Fires

A fire is determined to be out of control when direct firefighting yields no results or when conditions are too hazardous for the team to make an attempt at direct firefighting.

Filling or Sealing

In mines with sandfill available, the sandfill can be pumped into an enclosed area of the mine to entirely seal it. The enclosed area could also be flooded. However, these options are used only as a last resort.

Sealing Underground

The purpose of sealing a mine fire is to contain the fire to a specific area and to exclude the oxygen from the fire and eventually smother it. Sealing can also be done to isolate the fire so normal mining operations can be resumed in other areas of the mine.

Sealing mine fires is a complex issue with no single set of procedures—many factors determine the methods used. Either temporary or permanent seals can be built, and sealing is determined by the ICP depending on:

- The amount of explosive gases liberated in the mine
- Location of the fire
- Composition of overlying strata
- Building sites for the seals

TYPES OF FIRES

Electrical Fires

Electrical fires often occur when a problem with an electrical system generates sparks or causes a system to overheat, igniting insulation, transformer oil, or surrounding items on fire. These fires are generally manageable with an ABC fire extinguisher unless more equipment or items have become involved. Electrical fires tend to produce toxic gases and deplete the air of oxygen quickly while producing thick, black smoke.

Vehicle Fires

Vehicle fires can happen for a number of reasons, but typically occur from overheating parts, broken lines containing a flammable liquid, sparks contacting grease or other flammable components, or an electrical failure.

Most vehicles at a mine should be equipped with a fixed fire suppression system, capable of either automatic or prompt manual activation after the operator discovers a fire. Once a vehicle is fully engulfed or substantial flames are present, the fire should be determined unable to be combatted and the area should be cleared. Tires have the potential to explode once heated and can burn for many hours, hydraulic systems can fail catastrophically, and the fuel tank may burst into flames.

Ore Fires

Many mines extract combustible ores, and these are capable of catching fire when exposed to sufficient heat.

Coal

Coal can burn at temperatures exceeding 4,000°F and can burn in the seam for thousands of years while consuming the base commodity the mine is attempting to produce. Because of the extreme heat, coal fires can often fracture or partially recrystallize the surrounding rock, making firefighting even more hazardous. Coal fires should be fought indirectly, and the most successful attempts at fighting these fires have been with inert gas injection or inundation.

Pyrite

Pyrite is a sulfide ore mineral commonly found in gold or other metal mines. It is one of the few minerals capable of oxidizing so rapidly that it catches fire with an active flame front depleting oxygen from the area. Pyrite fires are rare but have been documented at mines in the past. The most effective way to fight a pyrite fire is by sealing the area and permitting the rock to cool completely.

Trash or Scrap Fires

Trash left to accumulate is often a source for fires underground. These fires start small and are often taken down and extinguished in this incipient stage. They can produce noxious gases in addition to carbon monoxide and can spread rapidly if they are adjacent to other flammable materials.

Shop Fires

Shops are common areas where fires occur. The causes often involve "hot work" (e.g., welding, cutting, grinding) and require the ignition of flammable liquids or other flammable materials. Typically maintenance workers can knock down or quickly extinguish these fires. However, if a shop fire begins to spread or to involve a vehicle, the area should be evacuated and more indirect means of firefighting should be attempted.

EXPLOSIONS

Causes and Effects

Explosions are caused the same way as fires and must have fuel, oxygen, and heat/ignition. The fuel can be an explosive concentration of gas. To avoid an explosion, the three elements must be kept separate.

Explosions can knock down timbers, damage ventilation controls, damage machinery, and ignite fires. Multiple explosions are possible; the disturbance to ventilation, and the buildup of smoke and combustion by-products can create explosive conditions following the first explosion.

Before Going Underground

The team should follow the same procedures discussed previously under “Firefighting Procedures.”

Indications of Explosion and Assessment of Conditions

First indications of an explosion may be reported by miners in the vicinity who may have felt a sudden movement of air, noticed smoke or dust in the air, or heard the sound of an explosion. Another indication may be a jump in the pressure recording chart for the main fan. The mine rescue team may find some evidence of an explosion which could be:

- The presence of carbon monoxide, carbon dioxide, oxides of nitrogen, sulfur dioxide, and other toxic and explosive gases in the main exhaust
- Blown-out timbers and bulkheads
- Overturned equipment
- Ground falls
- Film of dust on mine rail
- Smoldering fires and scorched material

The initial role of the rescue team after an explosion is to explore and assess conditions. Once this is completed, the teams, as directed by the ICP, will begin the process of re-establishing ventilation and recovering the mine.

Ground Control

Ground control is the process of maintaining the stability of rock in a desired arrangement. This can be done by many methods, some of which are more suited to permanent use, some better for emergency response and management.

ROCK BEHAVIOR

> **Placing rock into a compressional force regime and maintaining compressional forces is the key to ground control.**

Most materials can be characterized as behaving well under tensile or compressive forces. Steel, nylon, Kevlar, fiberglass, and most other modern materials are excellent under tensile loading as evidenced with the use of steel wire in suspension bridges, nylon in climbing ropes, Kevlar in body armor, and steel as beams in a structure. Rock behaves differently and is stronger under compression. Rock can often take hundreds of thousands of pounds of force when confined, permitting spaces to be opened and kept open in a mine thousands of feet beneath the surface. When rock is placed into tension, it breaks quite readily along planes of weakness, preexisting fractures, or compositional variations.

Assessing Ground Conditions

Ground conditions are most easily assessed with a three-point system: look, listen and feel.

Look

The surface of the rock must be visually inspected as a team advances. Areas of pronounced weakness tend to have more fractures visible on the surface, can be discolored, or may have water leaking more prominently through fissures. Also, the condition of permanent roof support must be inspected, noting if bolts have broken or fallen out, or whether mesh or shotcrete have failed.

Rubble on the floor is also a good indicator of failing rock from above. Fresh surfaces not coated in much dust or mud tend to be good indicators of recent rock fall, and close inspection of the roof above or nearby is warranted.

Listen

A scaling bar should be used to "sound" the surface of the rock. The rock should be struck with the point of the scaling bar, and the team listens to the sound when the rock and the scaling bar make contact. A sharp, solid ringing sound is a good indicator of solid ground, properly supported and very unlikely to move. A dull, drum-like sound, where it sounds like there is empty space behind the rock, is indicative of unstable rock. This should be scaled down with the scaling bar if possible or supported with a more effective means of ground support.

Rock movement is often audible, where moving (failing) rock is heard as a creaking or heaving sound, as rock actively fails.

Feel

While striking the rock with a scaling bar, attention must be paid to what is felt in one's hands as the rock is hit. If the bar bounces off and vibrates sharply (combined with a sharp sound), this is a good indicator of stability. A weak, soft, or crumbly feeling when the bar strikes the rock is an indicator of weak rock, and this should be scaled down or supported before the team advances any further.

METHODS OF GROUND CONTROL

Two general categories of ground control are:

1. Controls added to the rock permanently, and
2. Construction of shoring or other structures for temporary or permanent use.

Permanent Ground Control

Permanent ground control added to the rock is generally in the form of rock bolts. Many types of bolts exist, but each is inserted with the intent to achieve the same end goal, which is placing the rock into compression around the bolt site. As the rock is put into compression around the bolt, the rock mass is stabilized in the vicinity. More rock bolts are added as needed to stabilize the rock mass by placing all of the rock around the opening into compression (see Figure 13).

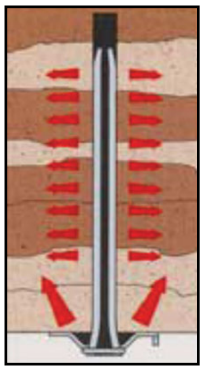


Figure 13 Spring-type rock bolts

Types of rock bolts:

- **Spring**—Spring steel rolled into a tube slightly larger than the intended hole diameter is forced into an opening, and spring resistance places rock into compression.
- **Inflatable**—Hollow (but closed) tube of sheet metal that is inserted into a drilled hole then expanded using compressed air or water to compress rock.
- **Mechanically anchored**—Expanding wedge anchor placed in the end of a drilled hole pulls tension on a steel rod attached to a plate placed on the rock face. The plate applies compression into the rock from that plate.
- **Resin bolt**—Steel rod inserted into a drilled hole with a resin cartridge that is broken open as the bolt is inserted. This resin quickly hardens and expands securing the bolt to the rock and placing the rock into compression.

Rock bolts are often supplemented with a mesh cover that is attached to the bolts. This mesh is meant to catch smaller falling rocks or provide internal support for shotcrete added later. In mines with characteristically weaker ground or with a lot of groundwater, shotcrete is added over the bolting and mesh to support the rock mass further and to add a measure of sealing to the rock.

Temporary Ground Support

When conducting exploration, there is rarely time to drill and bolt rock to stabilize. Instead teams must rely on scaling and constructing ground support. The construction of temporary ground support is a skill the team must practice to be truly competent and will allow the team members to become familiar with the materials that they have available.

Timbered Ground Support

The use of timbers as a means of ground support predates most other mining processes and is still used for temporary ground support in both mine rescue and urban search and rescue (USAR). The two key styles of timbered support used are box cribbing and the timber set.

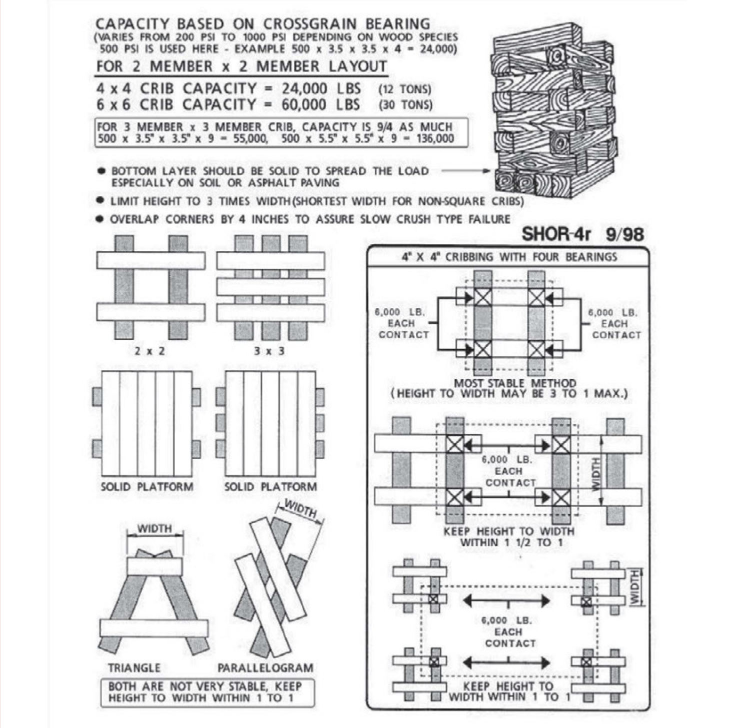
Box cribbing. Box cribbing uses square timbers, usually 4 in. × 4 in. or 6 in. × 6 in., to build a vertical stack of timbers in a two-by-two or three-by-three pattern. These timbers are aligned at right angles and have an overhang distance at the edges of at least the width of the timber. See Figure 14 for a visual example of box cribbing.

Box cribbing was developed for use in USAR, but is used in any application where rapid setup of a high-strength support is required.

Timber set. The timber set is a simple style that is particularly effective in a mine and provides a great deal of stability to the opening (see Figure 15). A timber set is characterized by a horizontal crosspiece with a pair of verticals hammered into place; forcing the rock into compression where it contacts. The 4 in. × 4 in. timbers are the smallest size used, with sizes up to a foot in width used in larger openings. Typically, some sort of shimming (wedges) is added to maximize the amount of contact between the support timbers and the rock itself, increasing the strength and effectiveness of the support system.

Mechanical Ground Support

Mechanical ground support uses the power of mechanical systems to place the rock in compression. These systems are most often



Courtesy of the Federal Emergency Management Agency.

Figure 14 Cribbing and capacities

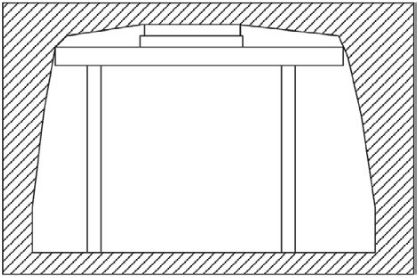


Figure 15 Timber set

Figure 16 Strut system

based around hydraulics or pneumatics and can support hundreds of thousands of tons. Most often, they are found in coal mines, as the hydraulic rams used in longwall shields. However, many fire and rescue groups stock and carry struts for use in support and shoring of collapsed structures.

Strut systems. Strut systems generally consist of a single bar, based around a hydraulic or pneumatic cylinder that can be locked into place once the support is in place (see Figure 16). These struts require additional training by individuals to gain proficiency in their use, but erecting strut systems can be much faster than building a timber set or a box crib support.

Communication

Effective communication is essential for the safe function of a mine rescue team and for the effective management of team members at a large-scale incident like a mine rescue. All team members are expected to be competent at communication, but the co-captain, those at the fresh air base (FAB), and the map person are expected to maintain a higher level of competence.

Effective communication in an emergency is concise, precise, and unambiguous. A message should be phrased to use the least number of words possible and in such a way that conveys your message exactly as you need it conveyed.

It is also critical to identify the origin of the communication and with whom you are trying to speak to ensure they acknowledge your call and are ready to receive. For example,

> "Command, this is Team One; [Message to command] [Message from team one]."

Mine disasters that require rescue teams to conduct search and rescue operations require special communication equipment. A variety of communicating devices exist that are applicable to different sets of circumstances.

RADIO PROWORDS

Certain words have been chosen as procedural words (prowords) to convey precise meaning and not be mistaken in the message (see Table 3).

Table 3 Prowords and their definitions

Proword	Definition
AFFIRMATIVE	That is correct, I concur, this message is correct, yes.
ALL AFTER	The portion of the message to which I have reference is all that which follows ______.
ALL BEFORE	The portion of the message to which I have reference is all that which precedes ______.
ALL STATIONS	All users on channel, listen to this message.
BREAK	Separating portions of a long message.
CORRECT	You are correct, or what you have transmitted is correct.
CORRECTION	An error has been made in this transmission. Transmission will continue with the last word correctly transmitted. An error has been made in this transmission (or message indicated). The correct version is ______.
GO AHEAD	Proceed to send your message.
I READ BACK	The following is my response to your instructions to read back.
I SAY AGAIN	I am repeating transmission or portion indicated.
I SPELL	Spelling the next word phonetically…
MAYDAY	Emergency situation, endangering life or operations. Precedence over all other traffic.
OUT	This is the end of my transmission to you, and no answer is required or expected.
OVER	This is the end of my transmission to you, and a response is necessary. Go ahead, transmit.
REPEAT	Say again, please.
ROGER	I have received your last transmission satisfactorily.
STAND BY	Please wait, will reply shortly.
WAIT	I must pause for a few seconds.
WAIT -- OUT	I must pause longer than a few seconds.
WILCO	I have received your signal, understand it, and will comply. To be used only by the addressee. Since the meaning of ROGER is included in that of WILCO, the two PROWORDS are never used together.

PHONETIC ALPHABET

The phonetic alphabet is used to spell over communication channels and is unambiguous in the pronunciation (see Table 4).

Table 4 International Telecommunication Union/North Atlantic Treaty Organization alphabet

Letter	Phonetic Equivalent	Pronounced
A	Alpha	AL FAH
B	Bravo	BRAH VOH
C	Charlie	CHAR LEE or SHAR LEE
D	Delta	DELL TAH
E	Echo	ECK OH
F	Foxtrot	FOKS TROT
G	Golf	GOLF
H	Hotel	HOH TELL
I	India	IN DEE AH
J	Juliet	JEW LEE ETT
K	Kilo	KEY LOH
L	Lima	LEE MAH
M	Mike	MIKE
N	November	NO VEM BER
O	Oscar	OSS CAH
P	Papa	PAH PAH
Q	Quebec	KEH BEC
R	Romeo	ROW ME OH
S	Sierra	SEE AIR RAH
T	Tango	TANG GO
U	Uniform	YOU NEE FORM
V	Victor	VIK TAH
W	Whiskey	WISS KEY
X	X-ray	ECKS RAY
Y	Yankee	YANG KEY
Z	Zulu	ZOO LOO

Any time you need to spell something over a communication channel, use a phonetic alphabet.

Other phonetic alphabets exist. Use the one with which your mine is most familiar.

DISTRESS AND EMERGENCY CALLS

In the event of an emergency with your team, the general procedure is for the co-captain to announce:

> "MAYDAY, MAYDAY, MAYDAY, [Identify the team], [State the emergency], [Provide other details], OVER"

All other traffic on that communication channel should cease immediately, and the responsible control station for the system takes over and collects information and dispatches resources. For example:

> *MAYDAY. MAYDAY. MAYDAY. This is Team One. We've had an apparatus failure at the base of the A helix. We are swapping to the spare apparatus. Send backup. OVER.*

COMMUNICATION DEVICES

Multiple types of communication devices exist that allow communication across a number of frequencies and mediums. Under no circumstances should a mine rescue team rely on a mine's existing communication system for the relaying of information vital to the rescue and recovery operation. Conditions may not be conducive to the functionality of the communication equipment, or the conditions may change as the rescue effort progresses.

Mine Phones

Most mines have a phone system that exists in all parts of the mine. This allows miners to communicate to other underground workers and the surface during normal mining activities. The phones operate in page mode. They broadcast messages to the entire mine's phone system at once, and simultaneous conversations are impossible. In the case of a mine disaster, the phone lines or power to the phone system may be severed, and these phones can become inoperable. If they survive, however, they can still be a means of communication to miners trapped underground in barricades or refuge chambers. Mine phones that the rescue teams come across during exploration should be tested for operability and possible response of trapped miners.

Leaky Feeder Systems

In addition to mine phones, leaky feeder systems may be implemented throughout underground mines. Leaky feeder systems are comprised of a radio antenna cable run throughout the mine, a main power station at the surface facility, amplifiers placed approximately every 1,200–1,600 ft along the antenna cable, and radios that communicate with the antenna. The radios used are typical handheld radios operating in very high frequency (VHF) to ultra high frequency (UHF). Radios within communicating distance of the antenna can communicate with any other radio that is within communicating distance of the antenna. During underground disasters, the leaky feeder antenna may be severed, eliminating its ability to communicate with the surface. Rescue teams exploring underground should test leaky feeder radios they may come across during exploration for operability and possible response of trapped miners.

Medium Frequency Radios

Medium frequency radios are the rarest of communication devices used underground. They are composed of a handheld case that is carried by the user of the device. They are portable but not easily carried by miners or rescue teams who need to use their hands. Medium frequency radios send voice communication over the medium frequency spectrum. The signal does not need a dedicated antenna to transmit or broadcast; instead it uses all metal objects in the drift as antennas. Pipes, rail, wire, equipment, and other existing utilities pick up and emit the medium frequency waves the radio produces. Bridges can be contained in the radios that convert UHF to medium frequency and vice versa, so that communication can be conducted using typical handheld radios. This type of communication is useful in the situation where all communications in a mine are severed, without power, or non-existing. The radio has its own power supply, so mine power is not required to send and receive messages. Because of the large amount of metal objects in a mine, radios tend to be more reliable.

Through-the-Earth Communication Systems

A recently introduced means of communication during rescue scenarios is through-the-earth (TTE) communications. This type of communication uses low-frequency radio waves to penetrate through solid rock from the surface to contact those underground. Voice and text communication is possible through the TTE systems developed to this day, though other types of data may be on the horizon. The communication system is composed of an underground unit and a surface unit. The underground unit is usually installed at a set location, commonly in a refuge chamber, while the surface unit is located directly above the underground unit on the surface. The surface unit sets up a very large antenna that is designed to receive the low-frequency waves that the underground unit emits. Communication can take place around 1,500 ft to 2,000 ft of solid rock. The prototype units are very large and not easily transported. Use of these devices is more for surface operations communicating directly with miners who are trapped underground and not for use by a rescue team conducting exploration underground. Improvements to these systems are currently being developed and will likely increase the portability and reliability of the system.

Gases and Ventilation

Under normal conditions, many gases are present in the mine atmosphere. The mine's ventilation system is designed to bring fresh air into the mine to disperse and remove the harmful gases and to supply oxygen to the working areas. During a disaster, fires or explosions may release dangerous gases into the atmosphere and/or a disrupted ventilation system could result in an oxygen-deficient atmosphere along with a buildup of toxic or explosive gases.

GAS DETECTION

Gas detection is a vital part of any rescue or recovery operation. The team will need to make frequent tests for gases and monitor any changes as they advance beyond the fresh air base (FAB). Important information to keep track of is what harmful gases are present, how much oxygen is in the atmosphere, and whether the gases present are unfit for breathing or explosive. Knowing which gases are present and the concentrations can help provide clues as to what happened. For example, the presence of carbon monoxide usually indicates a fire, and the amount of carbon monoxide helps the team make estimates regarding the extent of that fire.

Gas Detector Requirements

The Mine Safety and Health Administration (MSHA) requires mine rescue teams servicing underground metal and nonmetal mines to have four gas detectors that are equipped with sensors for the gases that may be encountered in each individual mine served. In addition, gas detectors must measure concentrations of methane from 0.0 to 100.0% of volume, oxygen from 0.0 to at least 20.0% of volume, and carbon monoxide from 0.0 parts per million (ppm) to at least 9,999 ppm [30 CFR 49.6 (a)(6)].

Any device containing electrical circuits such as methane detectors must be "permissible" to be used in mines classified as gassy. To become permissible, the detector must be tested by MSHA and found to be safe to use under such conditions.

Portable Gas Detectors

Portable gas detectors include, but are not limited to, devices such as carbon monoxide sensors, multi-gas detectors, and methane monitors. The team uses these devices, along with various gas detection tubes, to test the mine atmosphere repeatedly throughout exploration. Two common types of portable gas detectors are the multi-gas meter (Figure 17) and stain tubes (Figure 18).

Air Sampling and Chemical Analysis

Another method of testing for gases is to collect air samples in special syringes (Figure 19), evacuated bottles (bottles from which air has been removed), or gas or liquid displacement containers. These samples are then sent to a laboratory for chemical analysis or done at the mine site using portable equipment.

Although chemical analysis is generally more time-consuming than using a portable device, these analyses are more accurate, and

Figure 17 Multi-gas meter

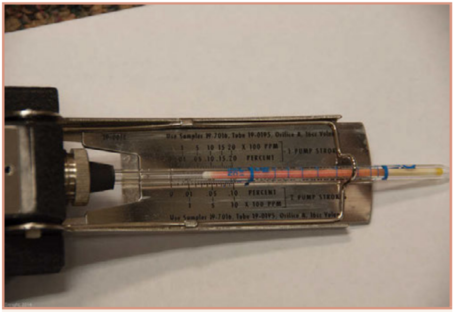
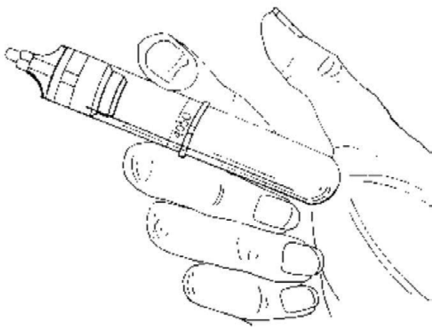


Figure 18 Stain tubes



Courtesy of the Mine Safety and Health Administration.

Figure 19 Special syringe for collecting air samples

cover a wider range of gases, giving precise information regarding which gases the sample contains and the exact concentrations.

Air samples are not used as frequently as portable detector readings, but they are still an important part of rescue and recovery operations. For example, a team may be required to take air samples from ventilation shafts and exhaust airways. This method is often used to acquire information about existing conditions underground before sending in a rescue team. Air samples can also be taken from behind sealed areas to determine when it is safe to breach the seal to begin recovery.

BASIC GAS PRINCIPLES

It is important to understand the characteristic and properties of each individual gas to accurately test for gases and to understand the results.

Physical Properties

Solids have definite shapes and volumes, and liquids have definite volumes but change shape based on the shape of the containers. A gas, however, has neither a shape nor a volume. It expands or contracts to fill the area in which it is contained.

Diffusion of Gases

The rate of diffusion is how quickly a certain gas will mix or blend with one or more other gases and how quickly it can be dispersed. Changes in atmospheric pressure and temperature can affect the rate of diffusion. For example:

- An increase in temperature causes a gas to expand.
- A decrease in temperature causes a gas to contract.
- An increase in pressure causes a gas to contract.
- A decrease in pressure causes a gas to expand.

Apart from changes in pressure and temperature, the rate of diffusion of a gas is also affected by the ventilation currents in the mine. The rate of diffusion is greatly increased by higher velocities and greater turbulence.

The pressure normally exerted on a gas is usually atmospheric pressure, which is measured on a barometer. A rise in the barometric reading indicates an increase in temperature and vice versa. Atmospheric pressure affects the rate of diffusion by causing the gas to either contract or expand.

High temperatures (or heat) cause gases to expand and diffuse more quickly. Consequently, the heat from fires will cause the gases to diffuse more rapidly. Lower temperatures work in the opposite way; gases respond to cold by contracting and diffusing more slowly.

Specific Gravity

Specific gravity is the weight of a gas compared to an equal volume of normal air under the same temperature and pressure. The specific gravity of normal air is 1.0 and acts as a reference point from which the relative weights of the other gases are determined. For example, if a certain gas is heavier than air, its specific gravity will be greater than 1.0.

The specific gravity of a gas indicates where it will be located within the mine and where to test for it. Gases in undisturbed air will stratify according to the specific gravity of the gas. Light gases or mixtures will stratify against the back, and heavy gases or mixtures will stratify along the floor.

Besides helping determine where to test for a gas, specific gravity also indicates how quickly the gas will diffuse and how easily it can be dispersed by ventilation. In still air, diffusion tends to be very slow, but under usual mine conditions, air currents from the ventilation system and convection currents cause a rapid mechanical mixing of gases within the air. Once the gases are mixed, they will not stratify again as long as the ventilating air currents remain constant, but will stratify again if the air currents are eliminated.

The lighter the gas, the more quickly it will diffuse. It is much easier to remove a concentration of light gas like hydrogen by ventilation than it is to remove the same concentration of a heavier gas like sulfur dioxide.

Explosive Range and Flammability

The range of concentrations within which a gas will explode is known as its *explosive range*. Figures representing the higher and lower limits of the explosive range are expressed in percentages. A gas that will burn is said to be *flammable*. A flammable gas can explode if there is enough of the gas in the air, enough oxygen, and a source of ignition.

Health Hazards

Some gases found in mines are toxic, referring to what happens either when they are breathed in or when the gas comes into contact with exposed areas of the body.

The degree to which a toxic gas will affect a person depends on three factors: (1) how concentrated the gas is, (2) how toxic the gas is, and (3) exposure duration. People will react differently to gases depending on their body type.

Each gas has a permissible exposure limit (PEL) established by the Occupational Safety and Health Administration (OSHA). A PEL denotes average concentrations of gases to which workers are permitted to be exposed over an 8-hour daily period. The PEL of a gas is typically expressed in parts per million (ppm).

If a toxic gas is harmful to inhale, a self-contained breathing apparatus (SCBA) offers protection from such gases, as long as it is working and fits properly. An SCBA cannot protect an individual from gases that are harmful to or absorbed by the skin. If an SCBA is used in petroleum-based fumes for a prolonged period of time, the fumes can eventually permeate its rubber parts and make the SCBA ineffective.

Solubility

The solubility of a gas is its ability to dissolve in water. Gases that are highly soluble can be released from disturbed water in a mine. When a mine is sealed off for any length of time, water can collect and release water-soluble gases into the air. Pumping or walking through water can release large amounts of soluble gases that would not otherwise be found in the mine atmosphere.

Color/Odor/Taste

Color, odor, and taste are physical properties of gases that can help identify a specific gas, especially during barefaced exploration. Hydrogen sulfide, for example, has a distinctive "rotten egg" odor. Some gases may taste bitter or sour, while others will taste sweet. Knowing the taste and smell of specific gases can help determine which gases should be tested for.

Asphyxiating Gases

Asphyxiate means to suffocate or choke. Asphyxiating gases cause suffocation by displacing oxygen in the air, producing an oxygen-deficient atmosphere. SCBAs will protect against asphyxiating gases by supplying the user with the necessary oxygen.

MINE GASES

Normal air is not a single gas, but is instead a mixture of several major gases and many trace gases (see Figure 20). Clean, dry air at sea level is made up of 78% nitrogen and 21% oxygen. The remaining 1% is made up of argon, carbon dioxide, and small traces of other gases such as neon, helium, xenon, hydrogen, methane, nitrous oxides, and ozone.

Air is normally colorless, odorless, and tasteless and supplies us with the oxygen necessary for life. However, during ordinary mine operation, normal air can become contaminated by things such as the carbon dioxide and water vapors miners exhale during respiration.

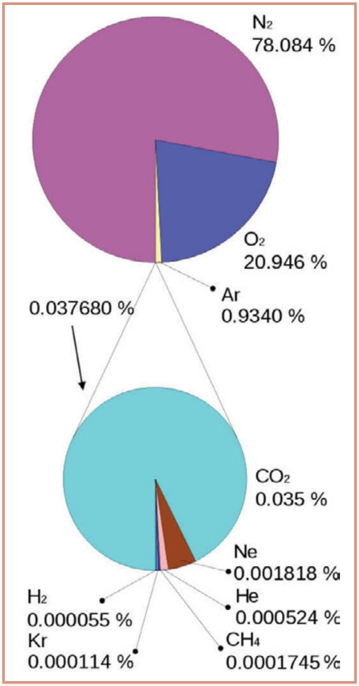


Figure 20 Normal air

One common source of contaminants in a mine atmosphere is blasting. The forces exerted on the mine's back, side, floor, and face may cause trapped gas pockets to escape into the mine air, and the blast itself may also produce carbon monoxide, hydrogen sulfide, or oxides of nitrogen. Even internal combustion engines and battery-charging stations have the potential to be sources of contamination due to the production of hazardous fumes. Normally, the contaminants produced by these sources are cleared out by the mine's ventilation system. During a disaster, however, the normal ventilation may not be effective.

Ventilation in a disaster can be disrupted because of many factors. For instance, fires and explosions can damage ventilation controls, and rock falls and bursts can obstruct the flow of air. In addition, the disaster itself may provide additional sources of contamination. Fires and explosions, for example, can release carbon monoxide into the atmosphere along with other dangerous gases.

The gases in a mine following a disaster will vary according to the type of mine and the disaster situation. Even the type of equipment (electrical, compressed air, or diesel) can affect which gases are present. Teams should know how to test for all the gases that may be present in the mines in which they will be required to respond. However, a team should always be monitoring oxygen and carbon monoxide.

COMMON MINE GASES

Following are detailed descriptions of mine gases, in order by specific gravity. A quick reference chart is included as Table 5.

Hydrogen (H_2)

Specific Gravity: 0.069594

Health Hazards: Hydrogen can be ignited easily at low temperatures, and is highly flammable. It can be an asphyxiant at high concentrations.

Table 5 Mine gases chart

Gas	Chemical Symbol	Specific Gravity	Explosive Range	Health Hazards	Solubility	TLV (TWA)*	Odor
Hydrogen	H_2	0.06	4.0–74.2%	Asphyxiant	Insoluble	—	—
Methane	CH_4	0.55	5–15%	Asphyxiant (rare)	Insoluble	—	—
Acetylene	C_2H_2	0.90	2.5–80%	Only slightly toxic. Asphyxiant (rare)	Insoluble	—	—
Carbon monoxide	CO	0.96	12.5–74.2%	Highly toxic. Can be an asphyxiant.	Insoluble	25 ppm	—
Nitrogen	N_2	0.97	—	Asphyxiant	Insoluble	—	—
Air	—	1.00	—	—	—	—	—
Ethane	C_2H_6	1.03	3.0–12.5%	Asphyxiant (rare)	Insoluble	—	—
Oxygen	O_2	1.10	Supports combustion	17%, panting; 15%, dizziness and headache; 9%, unconsciousness; 6%, death	Insoluble	—	—
Hydrogen sulfide	H_2S	1.18	4.3–45.5%	Highly toxic. Can be an asphyxiant.	Soluble	1 ppm (5 ppm)†	Rotten eggs
Carbon dioxide	CO_2	1.52	—	Increases breathing rate. May cause death in high concentrations.	Soluble	5,000 ppm	—
Propane	C_3H_8	1.52	2.12–9.35%	Asphyxiant (rare)	Insoluble	—	"Gassy"
Nitrogen dioxide	NO_2 N_2O_4	1.59	—	Highly toxic. Corrosive effect on lungs. May be an asphyxiant.	Reacts with water	0.2 ppm	Blasting powder fumes
Butane	C_4H_{10}	2.01	1.86–8.41%	Asphyxiant (rare)	Insoluble	1,000 ppm	"Gassy"
Sulfur dioxide	SO_2	2.21	—	Highly toxic. Can be an asphyxiant.	Soluble	0.25 ppm	Sulfurous
Radon	Rn	7.53	—	Exposure to radiation	Soluble	—	—

* Threshold limit valve (time-weighted average).
† Short-term exposure limit (STEL).

Air containing 4 to 74.2% hydrogen will explode even when there is as little as 5% oxygen present. Very violent explosions are possible when air contains more than 7 to 8% hydrogen. The presence of small quantities of hydrogen greatly increases the explosive range of other gases. At high concentrations, hydrogen can replace oxygen in the air and act as an asphyxiant. The most hazardous aspect of hydrogen, however, is the fact that it is highly explosive.

Solubility: Hydrogen is insoluble in water.

Color/Odor/Taste: Hydrogen is colorless, odorless, and tasteless.

Cause or Origin: Hydrogen is produced by the incomplete combustion of carbon materials during fires and explosions. It may also be liberated when water or steam comes in contact with hot carbon materials during firefighting. Battery charging also produces hydrogen.

Location Found: Hydrogen can be expected to be found in the vicinity of battery-charging stations (for lead-acid batteries), where explosives have been detonated, and after explosions. Hydrogen may also be detected during firefighting when either water or foam extinguishing methods are used. Hydrogen can also be expected to be found in an area that has been sealed to extinguish a fire. Because hydrogen is relatively light, it tends to collect in high places.

Detection Methods: Hydrogen can be detected with a multigas detector or by means of chemical analysis. Portable detectors should be held high when trying to detect hydrogen.

When to Test: Hydrogen should be tested for after any fire or explosion and near battery-charging stations in the mine. Hydrogen should also be tested for when water, water mist, or foam is used to fight fires.

Meaning of Findings: The presence of hydrogen could indicate that a fire or explosion has taken place. Elevated readings could also indicate that there is inadequate ventilation around battery-charging stations.

Methane (CH_4)

Specific Gravity: 0.55371

Explosive Range and Flammability: Methane is highly flammable, with an explosive range between 5 and 15% when there is at least 12.1% oxygen. Methane is most explosive, however, in the 9.5 to 10% range. Methane's explosive range is not an absolute measure of safety. There are other important factors to consider. For example, the presence of other combustible gases with wider explosive ranges or lower ignition points than methane may result in a more highly explosive mixture.

Health Hazards: Methane is not toxic. In high concentrations, however, it can cause asphyxiation by lowering the oxygen content of normal air.

The explosion of methane will frequently not cause significant destruction; often coal dust or other combustibles are propelled by the first (smaller) methane explosion, into the air and ignited, creating a massive fuel-air explosion that rapidly propagates through the mine.

Solubility: Methane is insoluble in water.

Color/Odor/Taste: Methane is colorless, odorless, and tasteless.

Cause or Origin: Methane may be liberated from the strata in metal/nonmetal mines when carbonaceous shale is penetrated and occasionally when carbonaceous rock is contacted or in the vicinity. Methane can issue in large quantities from sudden outbursts or from feeders, blowers, or clay veins in some mines. Methane can also be liberated by the decomposition of timbers and when water is removed from the mine.

Location Found: Because methane is relatively light, it collects in high places. Therefore, it can be expected to be found near the back of a mine. It may also be discovered at freshly mined areas, in poorly ventilated areas, and in abandoned or unused sections of the mine, especially where timbering is extensive. Because it is a relatively light gas (low specific gravity), methane is easy to disperse and be exhausted from the mine.

Detection Methods: A methane detector or chemical analysis can be used test for methane. Because methane is a light gas, the portable detector should be held high when testing for it.

Some gas detectors read %LEL instead of $\%CH_4$, which is a key attribute to be attentive to. Lower explosive limit (%LEL) detectors use a sensor that evaluates the potential for intake air to burn or explode, using a catalytic sensor to attempt to ignite the mixture. This will read a percentage of the lower explosive limit for the complete gas mixture (methane and more), up to 100%. This type of sensor will evaluate the presence of other gases, but will not provide a percentage methane present or a readily convertible figure to %CH4. Title 30 of the Code of Federal Regulations (30 CFR) requires that teams are equipped to read methane from 0 to 100% by volume, which an LEL sensor cannot read.

When to Test: In mines where methane is possible, testing should be done as often as necessary during exploration to determine the methane content of the surrounding atmosphere. Methane should also be tested for when normal ventilation is disrupted and when entering abandoned workings or removing water from old workings.

Meaning of Findings: If methane is present, it is important to monitor it carefully because methane is potentially explosive if there is enough oxygen present. If methane exists in potentially explosive concentrations or in combination with other gases that extend its explosive range, the team may be required to leave the mine.

Acetylene (C_2H_2)

Specific Gravity: 0.90

Health Hazards: Slightly toxic, but highly flammable. Acetylene can detonate when subjected to sufficient heat and pressure. Its explosive range in normal air is 2.5 to 80%.

Solubility: Acetylene is insoluble in water.

Color/Odor/Taste: Acetylene is colorless and tasteless and has a slight garlic odor when produced from calcium carbide lamps.

Cause or Origin: Acetylene is formed when methane is burned or heated in air having low oxygen content or older calcium carbide lamps. Carbide lamps drip water onto pieces of calcium carbide that will generate acetylene. The acetylene is then burned to produce light (often brighter than incandescent cap lamps).

Location Found: Acetylene is found after methane explosions in air having low oxygen content.

Detection Methods: A multi-gas detector or chemical analysis can be used to test for acetylene. It may also be recognized by its characteristic garlic odor. Because acetylene's specific gravity is near that of normal air, the portable detectors should be held at chest level when testing.

When to Test: Acetylene should be tested for after a methane explosion in air that is oxygen deficient.

Meaning of Findings: The presence of acetylene could indicate that an explosion has taken place in an area with low oxygen content, such as in a sealed area.

Carbon Monoxide (CO)

Specific Gravity: 0.9669

Health Hazards: Carbon monoxide is highly toxic even in very low concentrations and highly flammable. Carbon monoxide will poison a person's blood cumulatively over time, replacing oxygen, and can kill rapidly. Exposure to as little as 0.15 to 0.20% (1,500 to 2,000 ppm) carbon monoxide is extremely dangerous because it combines with the victim's red blood cells (the cells that carry oxygen bonded to hemoglobin throughout the body). Carbon monoxide combines with the hemoglobin 200 to 300 times more readily than oxygen, and once the cells have taken up carbon monoxide, they no longer have the capacity to carry oxygen. The first symptom of carbon monoxide poisoning is a slight tightening across the forehead and possibly a headache. Carbon monoxide poisoning is cumulative over time. As the victim continues to be exposed to the gas, the poisoning effects build up accordingly. As little as 500 ppm (0.05%) can kill an individual in a 3-hour time frame. Very few symptoms may be experienced before unconsciousness occurs.

Concentration	Symptoms
35 ppm	Headache and dizziness with 6–8 hours of exposure
100 ppm	Headache within 2–3 hours
200 ppm	Loss of judgment and headache
400 ppm	Headache within 1–2 hours
800 ppm	Dizziness, nausea, convulsions in 45 min; unconsciousness in 2 hours
1,600 ppm	Headache, tachycardia, nausea, dizziness in 20 min; death within 2 hours
6,400 ppm	Headache and dizziness within 2 minutes; respiratory and cardiac arrest within 20 minutes
12,800 ppm	Unconscious after 2-3 breaths; dead in 3 minutes

Solubility: Carbon monoxide is insoluble in water.

Color/Odor/Taste: Carbon monoxide is colorless, odorless, and tasteless.

Cause or Origin: Carbon monoxide is a product of the incomplete combustion of any carbon material. It is produced by mine fires and gas explosions. Carbon monoxide is produced by the burning or detonation of explosives and is emitted from the exhaust of internal combustion engines.

Location Found: Carbon monoxide is found during mine fires and after explosions or detonation of explosives. It can usually be detected near internal combustion engines.

Detection Methods: Carbon monoxide can be detected by means of carbon monoxide detectors, multi-gas detectors, or chemical analysis. Since carbon monoxide is slightly lighter than air, the portable detector should be held at chest level.

When to Test: During any team exploration, testing should occur as often as necessary to determine the atmosphere's carbon monoxide content, especially if fire is suspected.

Meaning of Findings: The presence of carbon monoxide higher normal ambient levels for a continued period of time definitely indicates the existence of a fire in the mine.

Nitrogen (N_2)

Specific Gravity: 0.96707

Health Hazards: Chemically inert—no fire or explosion hazard.

Nitrogen is nontoxic. However, in above-normal concentrations, it may cause asphyxiation because it lowers the oxygen content of the air.

Cause or Origin: Normal air contains approximately 78% nitrogen, making nitrogen the largest component of normal air. Nitrogen can be found following the detonation of some explosives.

Location Found: Increased nitrogen levels are often present after explosives have been detonated.

Solubility: Nitrogen is insoluble.

Color/Odor/Taste: Nitrogen is colorless, odorless, and tasteless.

Detection Method: Chemical analysis.

When to Test: Nitrogen should be tested for when it is suspected that the atmosphere is oxygen deficient and in abandoned or inactive workings where ventilation is inadequate.

Meaning of Findings: Elevated nitrogen content indicates an oxygen-deficient atmosphere.

Heavy Hydrocarbons (Ethane (C_2H_6), Propane (C_3H_8), and Butane (C_4H_{10}))

Specific Gravity:

Ethane – 1.0380
Propane – 1.5224
Butane – 2.00635

Explosive Range:

Ethane – from 3 to 12.5% in normal air.
Propane – from 2.12 to 9.35% in normal air.
Butane – from 1.86 to 8.41% in normal air.

Health Hazards: Ethane is highly flammable, and may explode in proper mixtures. Ethane can pose an asphyxiation hazard, but is not toxic or reactive.

Propane is extremely flammable, and is easy to ignite with any ignition source. Propane can also present an asphyxiation hazard and, if stored as a cryogen, can cause frostbite. Commercially produced propane is odorized, but propane created in other ways is odorless.

Butane is a highly flammable and slightly toxic hydrocarbon. Butane ignites easily, and is a mild hazard when inhaled, and with sufficient exposure, narcosis, drowsiness, asphyxia, and cardiac arrhythmias may result.

Solubility: All three are insoluble in water.

Color/Odor/Taste: All three are colorless and tasteless. In certain concentrations, propane and butane may produce a characteristic "gassy" odor. Ethane is odorless.

Cause or Origin: After mine fires, small concentrations of these gases are often detected along with methane. They also sometimes leak from gas or oil wells.

Location Found: The heavy hydrocarbons are often found in mines adjacent to oil or gas wells. Because they are heavy, these gases collect in low areas of the mine.

Detection Methods: Ethane, propane, and butane can be detected by portable detector or chemical analysis. Because these gases are relatively heavy, the portable detector should be held low when testing for them.

When to Test: These gases should be tested for following fires or explosions when methane is present. They should also be tested for if oil or gas casings are accidentally entered during mining operations.

Meaning of Findings: In significant concentrations, the heavy hydrocarbons can extend methane's explosive range. Elevated readings could indicate there has been a methane explosion or that there is seepage from an adjacent gas or oil well.

Oxygen (O_2)

Specific Gravity: 1.1046

Health Hazards: Oxygen is essential to life, but in high concentrations it can cause serious damage. Oxygen is not flammable itself, but it is a strong oxidizer; necessary for combustion.

Oxygen found in normal air is nontoxic. In fact, it is essential for life. It is harmful to breathe air that is low in oxygen, and breathing extremely oxygen-deficient air can kill a person. Individuals are accustomed to breathing air containing about 21% oxygen.

When the oxygen content of air drops to about 17%, a person will begin to breathe faster and deeper because the body is trying to compensate for the lack of oxygen. A 15% concentration will cause dizziness and headache. If the oxygen content of the air drops as low as 9%, the victim may lose consciousness. A 6% concentration or less is almost always fatal.

Solubility: Oxygen is insoluble in water.

Color/Odor/Taste: Oxygen is colorless, odorless, and tasteless.

Cause or Origin: Oxygen is the second largest component of normal air, making up about 21% of the atmosphere. There are four main causes of oxygen deficiency in the mine: (1) insufficient or improper ventilation that fails to bring enough oxygen to the work area, (2) displacement of the air's oxygen by other gases, (3) a fire or explosion that consumes oxygen, and (4) consumption of oxygen by workers.

Detection Methods: Modern electronic oxygen indicators are used to detect oxygen-deficient atmospheres. Because oxygen is only slightly heavier than air, the portable detector should be worn at waist level when testing for oxygen deficiency. Chemical analysis will also detect oxygen deficiency.

When to Test: During exploration, test as often as necessary to determine whether the atmosphere is oxygen deficient.

Meaning of Findings: If the main fan is still operating, an oxygen-deficient atmosphere could indicate that an explosion has taken place or a fire somewhere in the mine is consuming oxygen. Oxygen deficiency may also indicate that the mine's ventilation system has been disrupted.

Hydrogen Sulfide (H_2S)

Specific Gravity: 1.1765

Health Hazards: Hydrogen sulfide is both highly toxic and highly flammable. Hydrogen sulfide is approximately as toxic as hydrogen cyanide and carbon monoxide, and acts on several body systems, acting as a broad spectrum poison. High-level exposures, even with times as short as 5 minutes, can be immediately lethal from broad poisoning of the central nervous system. Long-term exposures of low concentrations can cause fatigue, loss of appetite, poor memory, dizziness, coughing, nausea, and pulmonary edema. Hydrogen sulfide is flammable and explosive in concentrations from 4.3 to 45.5% in normal air. It is most explosive at 14.2%.

Concentration	Effect
0.00047 ppm	Odor threshold—smelled by 50% of the population
10 ppm	OSHA PEL
10–20 ppm	Eye irritation
50–100 ppm	Eye damage
100–150 ppm	Olfactory nerve is paralyzed and sense of smell is lost
320–530 ppm	Pulmonary edema resulting in probable death
530–1,000 ppm	Strong stimulation of central nervous system. Causes rapid breathing and eventual respiratory arrest.
800 ppm	Lethal in 5 minutes
>1,000 ppm	Immediately lethal (single breath)

Hydrogen sulfide can be diagnosed with the discoloration of pennies in the pocket of a patient, and can help confine the mechanism of injury to a patient.

Solubility: Hydrogen sulfide is soluble in water.

Color/Odor/Taste: Hydrogen sulfide is colorless, and has a rotten-eggs odor and a slight sweetish taste.

Cause or Origin: Hydrogen sulfide is found in rocks that contain sulfur, generally where sulfide ores are present or where the rocks contain organic content. When acidic water contacts sulfide ores, hydrogen sulfide can be produced as it decomposes. The bacterial breakdown of organic materials will often create hydrogen sulfide as a natural by-product, resulting in the appearance of hydrogen sulfide in some shales, carbonates, and gypsum mines. Close proximity to oil and gas wells can be indicative, especially if there is a history of hydrogen sulfide in wells.

Location Found: Hydrogen sulfide is found in low places of the mine because it is a relatively heavy gas. It is often found in pools of water. In some mines, it may be found near oil or gas wells. Hydrogen sulfide may also be detected during mine fires. Because it is a water-soluble gas, hydrogen sulfide is often liberated from water in sealed areas of the mine when recovery crews walk through the water or begin pumping operations.

Detection Methods: Hydrogen sulfide can be tested for with a hydrogen sulfide detector, a multi-gas detector, and by chemical analysis. Because hydrogen sulfide is relatively heavy, the portable detector should be held low when testing for this gas. Hydrogen sulfide can be recognized by its distinctive “rotten egg” odor. However, continued exposure to the gas will dull the sense of smell, so this may not always be a reliable detection method. Eye irritation is another indication that hydrogen sulfide is present.

When to Test: Hydrogen sulfide should be tested for in poorly ventilated areas of the mine, during unsealing operations, after disturbing a collection of water, and following mine fires.

Meaning of Findings: A buildup of hydrogen sulfide could indicate that ventilation is inadequate. It might also suggest that excess water is accumulating in sealed or inaccessible areas of the mine or that there is seepage from an oil or gas well.

Carbon Dioxide (CO_2)

Specific Gravity: 1.51926

Explosive Range and Flammability: Carbon dioxide will neither explode nor burn.

Health Hazards: Carbon dioxide is mildly toxic and presents an asphyxiation hazard in large quantities. Persistent exposure to carbon dioxide can slowly poison a person, slowly replacing oxygen when bonded to hemoglobin. This poisoning, known as hypercapnia, poses the greatest hazard to miners trapped after a fire or in a refuge chamber, as they have been exposed to large quantities of carbon dioxide in the time it took for rescue teams to arrive.

Normal air contains about 0.03% carbon dioxide. When present in high concentrations (2% or higher), carbon dioxide causes individuals to breathe deeper and faster. Breathing air containing 5% carbon dioxide increases respiration 300%, causing difficult breathing. Breathing air containing 10% carbon dioxide causes violent panting and can lead to death.

Solubility: Carbon dioxide is soluble in water.

Color/Odor/Taste: Carbon dioxide is colorless and odorless and in high concentrations may produce an acid taste.

Cause or Origin: Carbon dioxide is a normal component of air and is a product of complete combustion (burning). Oxidation and the decay of timbers can produce carbon dioxide. Carbon dioxide is also a by-product of the respiration process. Fires, explosions, and blasting operations produce carbon dioxide, and in some mines it is released from the rock strata.

Location Found: Because it is relatively heavy, carbon dioxide will be found in greater concentrations along the floor and in low places of the mine. It also often shows up in abandoned workings, during fires, and after an explosion or the detonation of explosives.

Detection Methods: A carbon dioxide detector, a multi-gas detector, or chemical analysis can be used to test for carbon dioxide. Because carbon dioxide tends to collect near the mine floor, the portable detector should be held low.

When to Test: Carbon dioxide should be tested for after a fire or explosion. It should also be tested for when entering an inactive area of the mine or reopening a sealed area.

Meaning of Findings: Elevated carbon dioxide readings may indicate that a fire or explosion has taken place somewhere in the mine. High readings may also indicate an oxygen-deficient atmosphere.

Oxides of Nitrogen (Nitric Oxide (NO) and Nitrogen Dioxide (NO_2 or N_2O_4))

Specific Gravity: NO, 1.0359; NO_2, 1.5881

Health Hazards:

Nitric Oxide: Nitric oxide is extremely toxic when inhaled, and is a strong oxidizer, vigorously accelerating combustion. Exposure to small quantities creates nitric acid in mucous membranes, causing significant irritation at even low levels. Exposure to large concentrations of nitric oxide produces severe pulmonary edema, causing a person to effectively drown in their own fluids. Symptoms also tend to be delayed in appearance—patients can develop the severe pulmonary edema up to 72 hours after the exposure.

Nitrogen Dioxide: Nitrogen dioxide is a strong oxidizer and a highly toxic gas. Nitrogen dioxide forms nitric oxide in the mucous membranes (just like nitric oxide), and will cause pulmonary edema with sufficient exposure.

Solubility: Nitric oxide is insoluble in water, and nitrogen dioxide reacts with water to form nitric acid.

Color/Odor/Taste: Oxides of nitrogen are colorless at low concentrations and become reddish brown at higher concentrations. They smell and taste like blasting powder fumes.

Cause or Origin: Oxides of nitrogen are produced by burning and by the detonation and burning of explosives. They are also emitted from the exhaust of diesel engines. In the presence of electrical arcs or sparks, nitrogen in the air combines with oxygen (oxidizes) to form oxides of nitrogen. Nitric oxide does not exist in large amounts in the air because it readily combines with oxygen to form nitrogen dioxide.

Location Found: Because they are heavier than air, oxides of nitrogen tend to collect in low places in the mine. They can be found when electrical malfunctions produce arcs or sparks and after blasting operations.

Detection Methods: A nitrogen dioxide detector, a multi-gas detector, or chemical analysis can be used to test for nitrogen dioxide. The portable detectors should be held low when testing for these relatively heavy gases. Their characteristic reddish-brown color may be another indication that there is nitrogen dioxide present.

When to Test: Test for oxides of nitrogen should be done following a fire or explosion and after the detonation of explosives. Because diesel exhaust is a source of these gases, areas where diesel equipment is used should be tested.

Meaning of Findings: High oxides of nitrogen readings could indicate that there has been a fire or that explosives are burning. Malfunctioning electrical equipment producing arcs or sparks could also be the source. Ventilation is inadequate if diesel equipment is causing the elevated oxides of nitrogen readings.

Sulfur Dioxide (SO_2)

Specific Gravity: 2.21161

Health Hazards: Sulfur dioxide is a respiratory irritant and hazard in sufficient quantities. Sulfur dioxide creates an acid in the mucous membranes, and impacts the respiratory tract and eyes. Higher doses contribute to a greater hazard; eventually causing death.

As little as 0.04 to 0.05% (400 to 500 ppm) is dangerous to life. Even very small amounts of sulfur dioxide (0.001% or less/10 ppm or less) will irritate the eyes and respiratory tract. Larger concentrations can cause severe lung damage and may cause respiratory paralysis and the complete inability to breathe.

Solubility: Sulfur dioxide is soluble in water.

Color/Odor/Taste: Sulfur dioxide is colorless, but it has a bitter, acidic taste and a strong sulfurous odor.

Cause or Origin: Sulfur dioxide may be produced by blasting in sulfide ores and by fires containing sulfide ores. Sulfur dioxide may be released during the burning of some diesel fuels and by sulfide ore dust explosions. Volcanic activity in the vicinity will often generate or release sulfur dioxide; volcanic fluids generally release water vapor and sulfur dioxide, often causing water in hot springs to contain sulfur dioxide.

Location Found: Because it is relatively heavy, sulfur dioxide tends to collect in low places in the mine and near sumps. It can be expected to be found after some fires or explosions.

Detection Methods: Sulfur dioxide can be tested for by means of a multi-gas detector or chemical analysis. Because sulfur dioxide is a relatively heavy gas, portable detectors should be held low when testing for it. Sulfur dioxide's distinctive odor and taste and the respiratory tract and eye irritation experienced when exposed to it are also reliable indicators of its presence.

When to Test: Because it is highly soluble in water, sulfur dioxide should be tested for when stagnant water is disturbed. This gas should also be tested for following fires or explosions, and when sealed areas of the mine are opened after mine fires.

Meaning of Findings: High sulfur dioxide readings could indicate a mine fire or a sulfide ore dust explosion.

Other Information: Because of its high specific gravity, sulfur dioxide is hard to disperse by ventilation.

Radon (Rn)

Specific Gravity: 7.5267

Explosive Range and Flammability:
Nonexplosive and nonflammable.

Health Hazards: Radon is not toxic. However, radon and radon daughters—a decay product of radon—are radioactive. Continued exposure to high levels of these gases could result in lung cancer. Mines are required to keep exposure to radiation below 4 working level months (WLMs) per year. The exposure for any one month is limited to 1 WLM.

NOTE: The working level is a measure of the potential alpha particle energy of radon daughters in the mine atmosphere.

Solubility: Radon is soluble in water.

Color/Odor/Taste: Radon is colorless, odorless, and tasteless.

Cause or Origin: Radon is a gaseous decay product of the uranium series and is found in all uranium mines. It can also be liberated, but to a lesser extent, from almost any rock or soil. As radon is released into a mine atmosphere, it continues to decay and forms airborne particles the size of atoms called *radon daughters*. Radon daughters are particularly dangerous because they adhere to the dust that miners breathe. Once inhaled, they become deposited in the lungs where they continue to decay, giving off radiation and damaging lung tissue. Radiation can also be absorbed by the skin. If the radiation hazard in an area is very high, breathing protection and protective clothing may be required.

Location Found: Radon is mostly found in uranium mines. Stagnant air carries the heaviest concentrations. Also, pools of water will carry radon. Radiation levels can jump extremely fast when ventilation is disrupted.

Detection Methods: Survey meters are used to sample particulate matter in the air on a scheduled basis. Dosimeters can be used to monitor an individual's exposure.

When to Test: Regular tests are required in uranium mines or mines with a history of radon presence. Tests should be made when ventilation is disrupted and when opening a sealed area.

Meaning of Findings: Excessive readings could indicate a disruption of ventilation.

SMOKE, ROCK-STRATA GASES, AND THE DAMPS

Smoke

Smoke is the result of combustion and consists of tiny particles suspended in the air. The particles in smoke are made up of solid and liquid matter and usually consist of soot or carbon and tar-like substances such as hydrocarbons. Smoke itself is not considered to be an asphyxiant, but it usually contains carbon monoxide and other toxic, explosive, or asphyxiating gases produced by fires, making it dangerous to inhale.

Besides the dangers involved with inhaling smoke and its potential for explosion, smoke also limits the visibility in the mine. *This single factor adds an extra element of difficulty to any rescue or recovery operation.*

Rock-Strata Gases

Rock-strata gases can occur in some metal mining districts in the United States, particularly in Colorado and Nevada. Commonly known as rock gas, it is assumed to be largely carbon dioxide and is released from the rock strata under the influence of atmospheric pressure or by chemical weathering with the introduction of water or air. The presence of rock gas can produce an oxygen-deficient atmosphere, causing victims to suffocate if breathing protection is not worn.

The Damps

Damps are an obsolete series of names given to common mixtures of gases by early miners. A single name was attached to what was later learned to be a mixture of gases, generally based on its affect or other characteristics. A more detailed discussion of the damps can be found in other literature.

Victims

The primary objective of the mine rescue team, after ensuring team members' own safety, is to rescue the victims of an accident. A mine rescue team must be properly equipped to conduct a rescue and to extract patients from the mine.

This section is not meant to substitute for a course in first aid or emergency medicine, and it is encouraged that members of a mine rescue team become qualified at the first-responder level or greater. Generally, a victim is any person impacted by the disaster, alive or deceased. Patients are those that are alive and require medical care.

BASIC STEPS TO PATIENT MANAGEMENT

There are 12 basic steps to manage patients in a mine rescue. The team should:

1. Size-up the scene.
2. Put on proper personal protective equipment (PPE) (or body substance isolation, BSI).
3. Verify the number of patients.
4. Define the suspected mechanism of injury.
5. Identify any suspected spinal injury.
6. Assess the patient's level of consciousness.

7. Perform primary patient assessment, check patient's
   - Airway,
   - Breathing, and
   - Circulation.
8. Correct any major, immediate life threats.
9. Determine patient priority.
10. Perform secondary assessment.
11. Treat patient as properly and reasonably as the situation allows.
12. Package and transport patient.

When a team arrives at a patient, the team captain's primary role is to ensure scene safety. Once he or she does, the team medic then takes command of the team while the patient is being managed. The team captain will still direct team movement from the scene, but the medic has command of all matters relating to treatment and evacuation of the patient.

Simultaneously to patient treatment, the gas person should continue to assess gas conditions and ensure that respiratory protection is provided to the patient if the atmosphere is unsafe. The map person should determine the safest and most expedient route to the fresh air base (FAB) and advise the team captain and co-captain when it is time to evacuate the patient.

TRIAGE AND PATIENT PRIORITY

Upon encountering a single patient, one of the team's first goals is assessing the patient and determining his or her treatment priority. A patient's priority is generally based on the findings of the assessment and can be influenced by the circumstances of where the patient was found.

Patient Criticality

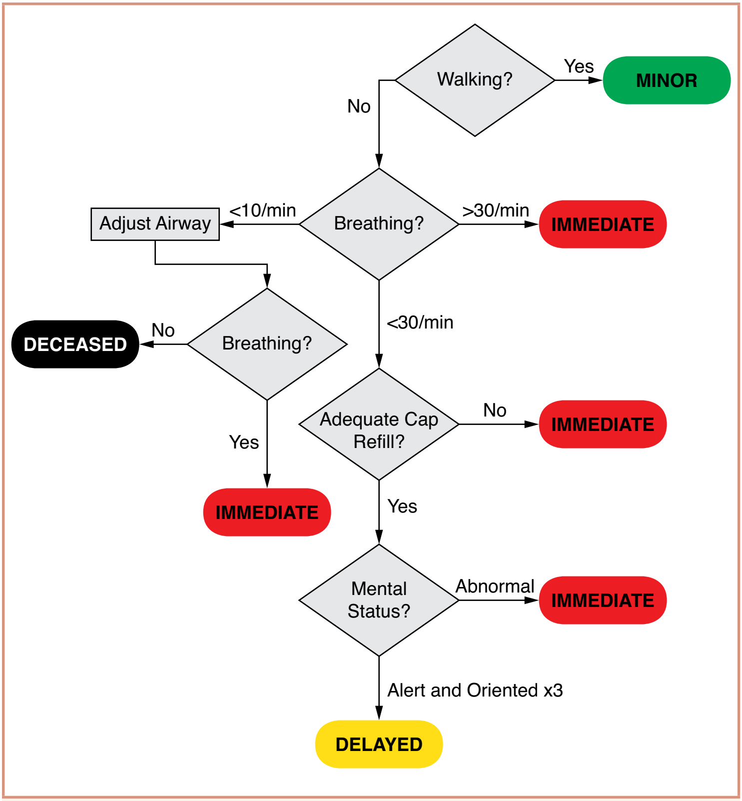
In general, patients with the following conditions are considered to be critical, requiring the patient to be evacuated to a hospital for immediate treatment:

- Poor or unstable vitals
- Amputation
- Two or more long-bone fractures
- Crushed or mangled extremity
- Pelvic fracture
- Flail chest
- Skull fracture
- Significant cervical-spine injury potential
- Poor airway
- Hypoxic
- Uncontrolled or severe bleeding
- Significant blood loss
- Altered mental status
- Sensory or motor deficit
- Signs/Symptoms of shock
- Multisystem trauma
- Penetrating head/neck/chest injury

For any of these patients, a trauma surgeon is more helpful than any work a mine rescuer can do in the field; therefore, these patients are of the highest priority to evacuate. For these cases, a rapid assessment and prompt evacuation is recommended, with a goal for on-scene time of 10 minutes. The optimal maximum allowable time frame, from the accident scene to the hospital, is 1 hour.

START System

The simple triage and rapid treatment (START) system is a simple and rapid assessment algorithm for multiple-casualty incidents



Source: Adapted from CITMT 2001.

Figure 21 START system (triage)

(MCIs). Any time there is more than one patient, triage should be undertaken to determine patient priority.

The START system is based on the flowchart in Figure 21, which shows how patients are sorted into one of four categories: Immediate, Delayed, Minor, Deceased.

Any patients who are categorized as *Immediate* (red) should be transported immediately to a trauma receiving center. They need to be transported from the scene of the accident to the hospital in a maximum of 1 hour and should be treated as critical. Patients classified as *Delayed* (yellow) will receive treatment, but their condition is such that they can be delayed treatment up to 2 hours. Patients classified as *Minor* (green) (or walking wounded) are the last to be treated and can be delayed for quite some time before they receive treatment.

Patients classified as *Deceased* (**black**) are considered either dead or nonsalvageable. Starting cardiopulmonary resuscitation (CPR) in an MCI does little to no good and ties up rescuers from being able to treat patients for whom they can help. Deceased patients are the lowest priority and are taken care of after all of the living have been attended to.

SURVIVORS IN A REFUGE CHAMBER

Refuge chambers are designed to be an alternative to escape for miners who may be in a deep or isolated section of the mine, where there is potential for escape to be blocked off.

Making contact with survivors in the refuge chamber is a critical first step for their mental (and physical) well-being. Making contact with them as early as possible is the goal, and this is typically helped by having the refuge chamber connected to the communications infrastructure in the mine.

Detailed instructions on extracting patients from a refuge chamber are shown in Figure 22.

Step One:

Observe conditions inside and make contact with survivors to determine conditions. Ensure no one is inside air lock before opening door for entry into the air lock.

Step Two:

Open outer door of refuge chamber; two team members may enter. Team captain with a gas meter and medic with trauma bag should be first. Co-captain should remain outside and in the same place, keeping in contact with the team members inside.

Step Three:

Close outer door with two team members inside. Flush out hazardous gases from the air lock, using either the mine compressed air or compressed air bottles in the air lock. Flush until air lock is completely cleared of smoke and atmosphere is at a normal range (verify with gas meter).

Step Four:

Open inner door and begin contact with survivors. Triage survivors based on injury significance and mental condition, then begin evacuation of survivors. Have survivors put on breathing protection while still inside the refuge chamber, then proceed through air lock (without having both doors open simultaneously).

Repeat this process until all survivors have been evacuated.

Figure 22 Extracting a patient from a refuge chamber

Humans use about 1 cubic yard of air per hour.

To assess time remaining:

1. Determine volume of area enclosed

   $$Volume = Length \times Width \times Height$$

2. Determine time barricaded
3. Time remaining =

   $$T_{remaining} = V - (T_{barricaded} - T_{now})$$

All times are in hours; all lengths in yards.

Figure 23 Time remaining in a barricade

SURVIVORS IN A BARRICADE

Miners are trained to barricade themselves in the event they are unable to escape and the atmosphere is becoming contaminated. Typically these barricades block a small spur drift, or another fairly small area, using a brattice cloth and are built to keep a safe, breathable atmosphere behind the barricade.

Contact with these survivors is more crucial than contact with those in a refuge chamber. Barricades typically lack the supplies found in a refuge chamber, and the well-being of survivors is in more jeopardy under these conditions. See Figure 23 on assessing viable time remaining in a barricade. When the team captain makes contact with those in a barricade, he or she must find out:

- How many people are inside? Who they are?
- How large is the barricaded space?
- How is the air?
  - Do the survivors have a gas detector?
- Have they used their self-rescuers?
- Is anyone injured?
- Is there a source of clean air into the barricade?
  - Have rescuers broken open a compressed air line?

- Do survivors have any information about the circumstances of the accident?

O_2 < 17.0%
CO > 1200 ppm
H_2S > 100 ppm
NO_2 > 20 ppm
SO_2 > 100 ppm
CO_2 > 4.0%

Figure 24 Barricade limits

All of the information collected should be used to guide a decision on how rapidly the survivors need to be extricated from the barricade. The first concern is the gases present (see Figure 24). Hazardous gas concentrations inside the barricade would warrant swift evacuation of the survivors. The second concern is oxygen depletion of the atmosphere inside; as survivors are breathing, they consume oxygen and add carbon dioxide to the space they sealed.

When dealing with survivors in a barricade, the mine rescue team should:

1. Ensure gas conditions outside the barricade are below barricade limits.
2. Build an air lock.
3. Breach the barricade.
4. Extract survivors.

Mine Recovery

Once all rescue efforts have ended, the mine rescue team's main objective is to effectively and efficiently recover the mine to a fully operational condition. The team members should be able to re-establish ventilation after a mine disaster and identify the supplementary work necessary to restore the disaster area to normal operation.

ASSESSING CONDITIONS

Before executing a recovery operation, the mine rescue team must perform an initial assessment of underground conditions. This assessment is necessary to ensure the team's safety during recovery work and to determine what rehabilitation work is needed to recover the affected area. As the recovery work progresses, the rescue team will continually report any changes in underground conditions and any additional damages it encounters.

The following checks should be included in the primary underground assessment:

- Damage to the ventilation system
  - Condition of ventilation controls
  - Condition of auxiliary fans and tubing

- Gas levels
- Ground conditions
- Condition of track
- Condition of water, air, power, and phone lines
- Evidence of flooding or flood damage
- Presence of smoldering debris or hot spots in fire areas

RE-ESTABLISHING VENTILATION

The main task of the mine rescue team during the recovery operation, other than team safety, is to re-establish ventilation and bring fresh air to any areas damaged by fires or explosions. Other mine personnel, including regular work crews, are able to help with the recovery efforts once the air is clear and safe conditions are re-established throughout the mine.

Areas Damaged by Fires or Explosions

In a fire area that has been previously sealed, the mine rescue team must unseal the area, assess the damage, and repair and rebuild the ventilation system. This same procedure applies to restoring a fire area that has not been sealed, but usually re-establishing ventilation in these areas is less complicated. In areas damaged by explosions, there must be damage assessment and repairs made to ventilation controls, but extensive construction work may be necessary to fully restore ventilation because of extreme damage to the area.

Unsealing a Fire Area

To restore ventilation to sealed areas, company mine officials meet with federal, state, and union representatives to create a step-by-step process and plan. Mine rescue team members are not involved in the planning process for unsealing fires but must be aware of all the hazards and conditions taken into account by the planning committee. Opening seals prematurely without proper planning could cause reignition of the fire and possible ignition of any explosive gases present, so the unsealing operation must be planned very thoroughly.

The final decision to unseal a fire area is made by the Incident Commander after consultation with experts and an understanding of the conditions and consequences.

When to Unseal a Fire Area

The safest time to unseal the fire area must be determined through careful analysis of conditions surrounding the vicinity. The following factors must be taken into consideration when governing the time for unsealing a fire area:

- Extent and intensity of the fire at the time of sealing
- Characteristics of the burning material and surrounding strata
- Tightness of the seals
- Effect of barometric pressure on the enclosed area
- Effect of temperature on the enclosed area
- Location of the fire area with respect to ventilation
- Gas conditions from analysis of air samples taken from behind the seals
  - Oxygen
  - Carbon dioxide
  - Carbon monoxide
  - Methane
  - Hydrogen
  - Nitrogen
- Proximity of gas wells to the fire area
- Size of the sealed area

Required Conditions for Unsealing a Fire Area

No attempt to unseal a fire area should be made until the following requirements are met:

- Oxygen content of the air behind the seal is low enough to prevent an explosion, independent of the quantity of combustible gases behind the seal;
- Carbon monoxide, the gas that indicates that combustion has taken place, is not present in the area behind the seals; and
- Enough time has passed to ensure that the area behind the seals has cooled to prevent rekindling of the fire when air is introduced during unsealing operations.

Preparations for Unsealing a Fire Area

The mine rescue team prepares to open a sealed fire area by:

1. Adjusting ventilation so that toxic and explosive gases released from the sealed area are directed into the main exhausts.
   - The exhaust airways should be checked for any possible ignition source, such as mine phones or signaling lights, and all potentially dangerous ignition sources should be removed.
2. Stationing a team member at the main fan to ensure proper operation during mine recovery and at the main exhausts to continuously monitor gas levels exiting the mine.
   - All teams working underground should be withdrawn immediately if the fan begins to slow down or malfunction in any way.
   - If the fan is electrically driven and exhausting, the team must take all necessary precautions to ensure that explosive gases do not come into contact with the fan motor or other electrical equipment in the area.

3. Ensuring that electrical power to the sealed area has been cut off before beginning to unseal the area.
   – This is especially important in mines with explosive gas accumulations. However, cutting off the power may not be advisable in some mines or some situations—for example, if it is necessary to operate pumping equipment.
4. Ensuring that all personnel, except the mine rescue team, have exited the mine.

Methods of Unsealing a Fire Area

There are two basic methods for unsealing a fire area:

1. Progressive, or stage, ventilation
2. Direct ventilation

> **The oxygen content of the air in the sealed area must be reduced to at least 2% before air locking into the area.**

Recovery by progressive ventilation. This method involves exploration and reventilation of a sealed area in successive blocks using air locks and is most commonly used in single-level room-and-pillar mines. It is also commonly used when the sealed area is large, the fire was very extensive, or bodies must be removed from the area. Progressive ventilation allows for careful control of gas conditions and can be halted immediately if conditions become hazardous, especially because some air will unavoidably enter the area behind the seals during reventilation. Team members should be aware that this process can be very slow and time-consuming.

Recovery by progressive ventilation is similar to advancing a fresh air base (FAB) but is usually a slower process because of extensive damage found in the sealed area and the size of the blocks being reventilated.

The procedure for progressive ventilation by the mine rescue team is as follows:

1. Build an air lock at one of the seals on the intake side of the fire area.
2. Ensure there are adequate conditions for entering the sealed area before entering the air lock and breaking out an opening in the seal. The team must be under apparatus for the entire reventilation process.
   - The team may have to wait for the pressure to stabilize after removing the first few blocks from a seal.
3. Enter and explore the sealed area to assess conditions to the point where the next air lock will be built, dependent on the conditions encountered and the amount of construction work needed. (There is usually between 100 and 500 ft between air locks.)
4. Continuously monitor conditions in the sealed area. This monitoring includes checking temperature readings; testing for oxygen; carbon dioxide, carbon monoxide, and explosive gases; and collecting air samples when requested.
5. After completion of the exploration and assessment, construct the next air lock and any necessary bulkheads needed in parallel passageways to reseal the area and ensure the air is directed to an exhaust airway.
6. Leave the area once it has been checked for any remaining fires. Reventilation is begun by opening a seal on the exhaust side first, followed by one of the seals on the intake side.
7. When working near the origin of the fire, remove any heated materials from the area before reventilating.
8. Continue this process to recover the entire sealed area, as long as the fire remains extinguished.

Recovery by direct ventilation. This method involves recovering and reventilating an affected area as a whole, all at once, instead of in successive blocks and is used in both single-level and multilevel mines. If more than one level has been sealed, the higher level should be unsealed first, working down through the lower levels progressively to ensure that the mine rescue team is not working below unknown conditions.

Before using direct ventilation, there should be conclusive evidence that the fire has been extinguished.

For recovery by direct ventilation, the rescue team procedure is to:

Air locking should always begin on the intake side of the fire.

1. Build an air lock at an intake seal to allow the rescue team to enter the sealed area.
2. Continuously monitor conditions in the sealed area. This monitoring includes checking temperature readings; testing for oxygen, carbon dioxide, carbon monoxide, and explosive gases; and collecting air samples when requested.
3. After testing and observation of the area, return to the FAB and begin the unsealing process once conditions are adequate.
4. Break open a seal on the exhaust side and the air lock and also open the air lock just built by the team to allow airflow. Attempt to keep any combustible gases in the main exhaust below the lowest explosive limit.

Periodic sampling and analysis of the exhaust air will indicate the quality of the air still inside the mine and govern the time period that must pass before rescue personnel are allowed to reenter the mine. The Command Center will determine when reentry is safe.

It may be advisable, especially with a large affected area, that a mine rescue team under apparatus is the first to reenter and recheck gas levels underground.

Reventilation After an Explosion

The methods for reventilating after an explosion are the same as the methods used for reventilating a sealed fire area. During exploration of the area and preparation for ventilation, the mine rescue team should be extra alert watching for any possible sources of ignition and eliminating them immediately.

CLEARING AND REHABILITATING THE AFFECTED AREA

The mine rescue teams may need to perform some extensive construction and cleanup work while advancing ventilation under apparatus. Once the affected area is completely cleared of any dangerous gases, labor crews can assist with cleanup. This work includes, but is not limited to:

- Building and repairing damaged ventilation controls
- Hauling out falls and hot materials
  - Important for eliminating possibility of rekindling a fire after unsealing a fire area
  - Material should be wetted down before and during the loading operation
- Stabilizing ground conditions
  - Often weakened by fires or explosions
  - May need extensive timber supports and cribbing
- Pumping water
  - Advance fresh air to the area before pumping and carefully monitor gas levels, especially water-soluble gases
  - Use nonconducting suction lines
  - Watch for weakened ground conditions in watery areas

- Repairing air, water, and power lines
  - Power is progressively restored by an electrician along with advanced ventilation
- Clearing roadways and tracks
- Re-establishing communication lines

Team Safety

MEDICAL CRITERIA

Before team members begin rescue work of any type, the lead medic, in coordination with the team captain, must be certain that team members meet the following criteria for work.

Vital Signs

Table 6 shows the *normal* and *acceptable* ranges for vital signs of a team member.

Table 6 Normal and acceptable ranges for vital signs

Blood pressure (systolic):	90–140 mmHg	Blood pressure (diastolic):	60–90 mmHg
Heart rate (max):	70% of 220 – age (years)	Heart rate (min):	50 bpm
Core temperature:	94–100.5°F	SpO_2:	90–100%

Physical Condition and Recent History

The following physical conditions are reasonable criteria for a rescuer to be excluded from entry:

- Open wounds, sores, rashes, burns, or recent injury that may prevent function

- Altered mental status, including
  - Slurred speech
  - Abnormal weakness
- Recent illness (within past 72 hours)
  - Nausea
  - Vomiting/diarrhea
  - Infection
- New (within past week) medications
- Alcohol intake within past 6 hours (if heavy drinking to intoxication, 72 hours)
- Any other substantial medical condition that may endanger self or others

POST-WORK REHABILITATION

It is essential for the health and welfare of team members that they receive proper rehabilitation and medical monitoring post-work, and team leadership must ensure that these post-work rehab policies are followed. Team medics are responsible for ensuring that proper rehab is done by team members at either a training or incident scene and should coordinate with team leadership the times and supplies to make this happen.

Self-Rehabilitation

Following work under oxygen for no more than 1 hour without strenuous work being done (limited perspiration, no fatigue) or any other work without apparatus at moderate difficulty, team members must take a 20-minute self-rehab break. During this break, team members should:

- Remove personal protection equipment (PPE)
- Remove closed-circuit breathing apparatus (CCBA) and other rescue equipment

  - Other team members should be responsible for cleaning and preparing CCBAs for further use
- Sit down comfortably
- Drink at least 0.5 L of water or other fluids

If a team is to return to work, the team captain and medic must be certain that the team has completed the rehab session and is prepared to go back to work. Team members should be checked to meet the base medical guidelines specified previously if any uncertainty exists.

Formal Rehabilitation

Following work under oxygen exceeding 1 hour at moderate to strenuous difficulty, or work without apparatus at strenuous difficulty, team members must enter a formal rehab and take a 45-minute (minimum) break.

A specific area should be set aside for formal rehab, sheltered from the elements, with seating and refreshments for the team members. Upon completion of work, team members report to the rehab area and should:

- Remove all PPE and heavy clothing
- Remove CCBA
- Sit down comfortably out of the elements
- Consume at least 0.5 L of water
- Consume at least 0.5 L of a sports drink
- Consume at least 300 calories of food of mixed type
  - Roughly equivalent to three granola bars.
  - Should include protein, carbohydrates, and sugars
  - May be skipped if team is breaking for lunch

After team members have completed the 45-minute break and consumed all the fluids and food required, each must receive

Table 7	Vital signs needed to return to work after rehab		
Pulse:	<125 bpm	Blood pressure (diastolic):	135
Temperature:	<100°F	Blood pressure (systolic):	90
SpO_2:	>90	NOTE: If SpO_2 is abnormally low, check apparatus function and SpCO levels.	

a medical check before being permitted to depart rehab. Team members must meet the guidelines in Table 7 before returning to work.

If team members exceed these guidelines by a substantial amount (e.g., heart rate greater than 180 bpm), team members should receive formal medical evaluation by emergency medical services (EMS) personnel. Team medics should be prepared to request assistance from local EMS for members with vitals out of normal ranges.

Conditional Concerns

Extremes in weather and conditions require modifications to these procedures. Team members should be checked initially to ensure proper PPE and clothing for the incident conditions, and rehab should be modified accordingly. Suggested modifications for conditions are outlined in Table 8.

These suggestions are meant as guidelines and may be modified as needed by the lead medic at an incident or training.

Logistical Requirements

Team leadership should be prepared to handle the logistics of team rehab. Time for rehab should be budgeted into each training activity, and purchase of supplies beforehand is essential.

Table 8 Vital signs modified for conditional concerns

Weather and Working Conditions	Modifications
Temperature <32°F:	Warm beverages +0.5 L
Temperature 32–40°F:	Warm beverages
Temperature 90–100°F:	+10 min to rehab
Temperature >100°F:	+20 min to rehab and 0.5 L of fluids
Humidity 70–90%:	+5 min to rehab and 0.25 L of fluids
Humidity >90%:	+20 min to rehab and 1 L of fluids
Altitude 8,000–10,000 ft:	+5 min to rehab and 0.25 L of fluids
Altitude >10,000 ft:	+0.5 L of fluids (verify SpO_2)

Suggested Equipment List

All events:

- Blood pressure cuff and stethoscope (at least two sets)
- Pulse oximeter
- Rehab checklist
- Bottled water or team members with adequate water on hand

Anticipated strenuous work:

- 5-gal jug of water (full)
- Cups
- Ice
- Sports drink powder, premeasured for jug (in packets)
- Granola bars, at least two per team member
- Shade pop-up (if needed)

A Medical Observation Log Sheet is provided in Figure 25.

Event Name					
Date:	Temperature:		Location:		
Name:		BP	HR	RR	SpO_2
	Entry				
Time in/out	Exit				
Name:		BP	HR	RR	SpO_2
	Entry				
Time in/out	Exit				
Name:		BP	HR	RR	SpO_2
	Entry				
Time in/out	Exit				
Name:		BP	HR	RR	SpO_2
	Entry				
Time in/out	Exit				
Name:		BP	HR	RR	SpO_2
	Entry				
Time in/out	Exit				
Name:		BP	HR	RR	SpO_2
	Entry				
Time in/out	Exit				
Name:		BP	HR	RR	SpO_2
	Entry				
Time in/out	Exit				
Name:		BP	HR	RR	SpO_2
	Entry				
Time in/out	Exit				
Name:		BP	HR	RR	SpO_2
	Entry				
Time in/out	Exit				

Figure 25 Medical Observation Log Sheet

Additional Health Hazards

HOT WEATHER

Heat Injury

Heat injury is considered a nontraumatic injury and, unlike burns, occurs from sustained exposure to temperatures so that the body cannot maintain the normal core temperature of 98.6°F. Heat injury can occur any time individuals cannot cool themselves as quickly as they warm. This most frequently can occur in hot weather and can be amplified by clothing.

Hot weather is the most common cause of heat injury for the general public, but other people are particularly susceptible, especially first responders. Firefighters and rescuers are prone to overheating when wearing protective clothing. They should be particularly aware of this concern and monitored by medical personnel.

Heat Cramps

Heat cramping is not strictly the same as heat exhaustion or heat stroke, but occurs when chemical imbalances from improper or inadequate hydration impair muscle function at a cellular level. This most commonly occurs when athletes are physically exerting themselves in hot climates and drink only water (and typically not enough). Treatment for heat cramping is fairly simple: adequate rehydration (with electrolyte replacement), passive cooling of the patient, and gentle stretching of the cramped area.

Heat Exhaustion

Heat exhaustion is the physiological response to the body core temperature beginning to exceed normal ranges and is a preliminary condition before heat stroke. The body attempts to cool down and adjust to the temperatures as best as possible by drastically dilating peripheral blood vessels and increasing sweat production. This can be quite helpful; however, when this continues for too long, simple vascular compensation turns into shock. The decreased blood volume and peripheral dilation cause a drop in adequate blood flow to the central organs and, if the patient is standing and walking around, affect the brain first. Sweating is increased to the point where the patient can appear drenched in sweat, and the skin is hot and flushed. The shunting of blood from the brain causes drowsiness, confusion, light-headedness, and may occasionally cause a syncopal episode.

Treatment for heat exhaustion should not be delayed upon recognition of the condition and involves some critical steps:

1. Passive cooling of the patient
   - Move the patient to somewhere with a break from the heat.
   - Do not apply cold packs.
2. Rehydration
   - Include electrolytes.
3. Shock management
   - Lay the patient down, elevating the legs.
   - Give the patient oxygen if indicated by saturation.

Heat Stroke

Heat stroke is a life-threatening condition during which the body is unable to regulate temperature any further and has lost the ability to cool itself from extremely high temperatures. This is a later stage from heat exhaustion, and many of the same signs and symptoms are amplified. The patient is *no longer able to sweat*, with skin hot and dry to the touch, and the patient will present with a drastically altered mental status. The patient will be lethargic to combative, confused, truly delirious, unable to think cogently or make effective decisions, and will eventually become unconscious as the condition worsens. A patient with heat stroke is an emergency situation and must be treated as such.

Treatment for heat stroke should be much more aggressive and undertaken as soon as the condition is recognized. Providing the patient shade or a cool environment is the first priority, so the patient should be moved into whatever shade is available or shade should be created. Active cooling, which should begin as soon as exposure to heat is over, involves placing ice packs in the armpits and groin and over the wrists. Remove any tight or constricting clothing, allow air to circulate over the patient, and spray the patient with water if possible. The patient should be evacuated to a hospital as soon as possible.

Hydration

The human body uses water for most processes and for thermal regulation. Under resting conditions, an average person requires about 3 L of fluid (under normal conditions at moderate altitude) per day to stay properly hydrated. Unfortunately, most people are dehydrated on a day-to-day basis, and this is hazardous with increased heat. Research has shown that proper hydration effectively prevents heat injury, even in temperatures above 105°F while doing strenuous work.

A simple statement of "3 liters per day" is not accurate when conditions are anything beyond normal, and definition of *adequate hydration* should increase any time these conditions are different. Examples:

- Heat >95°F
- Humidity >60% or <10%
- Physical exertion
- Stress

Any time these conditions are present, more than 4 L of water should be consumed in a day. In harsh desert conditions, hikers are recommended to drink 5 L per day.

Electrolyte Replacement

Sweat is the primary human cooling mechanism and uses a salty solution to cause heat loss by evaporation. With extensive sweating (such as when working in hot weather), salt is lost in substantial quantities as sweating proceeds. This sweat must be replaced for adequate body function to proceed and can exacerbate dehydration and other heat injuries. For every few liters of water, it is beneficial to eat salty foods (trail mix, etc.), or to consume a drink with some salt (limit the sugar, caffeine, etc.).

Prehydration

Prehydration is the process of drinking enough water in advance of substantial exertion to bank water for when it cannot be replaced. This practice is helpful before situations when one will not be able to drink water (going under apparatus, periods where lengthy focus is required, etc.) and helps prevent dehydration later on.

Rescue team members must ensure they drink adequate amounts of water over the day and replace lost salts if sweating notably. Adequate hydration earlier prevents injury or incapacitation later.

ALTITUDE

Altitude creates a series of unique concerns in addition to other climate- or weather-related situations. As a team member ascends in altitude, the barometric pressure (ambient pressure from the atmosphere) decreases, causing the air to be "thinner" as he or she gets higher. Both humans and equipment are subject to altitude effects, and proper knowledge of these potential problems is essential for a team that may be at high altitudes.

Impact on Humans

Humans are susceptible to altitude effects when not given adequate time to acclimate. A lack of oxygen is the primary factor, as the altitude causes the atmosphere to become thinner and thinner as it increases. High altitude is broken down into three basic zones, described following:

- **6,500 to 11,500 ft**—This range is the lowest of the three altitude zones. People newly arrived to this elevation generally observe a decrease in athletic performance, as well some mild insomnia and dehydration. This presents in the more susceptible individual as acute mountain sickness.
- **11,500 to 18,000 ft**—This elevation is where altitude sickness truly takes effect. It is the highest range individuals commonly experience in North America, as all but the highest peaks in the United States are in this altitude range. A person rapidly ascending to this altitude is at a genuine risk, because this elevation causes each of the different types of altitude illness. This range is usually considered in literature to be a "high" altitude.

- **18,000 to 29,000 ft**—The highest elevations on Earth fall into this range. Individuals entering this range are at extreme hazard for altitude illness, particularly when higher than 20,000 ft above sea level. This maximum range, higher than 20,000 feet, is known as the *death zone*. Humans cannot acclimate to these conditions; even those in top physical condition deteriorate over a course of days to weeks.

Human Response

As humans ascend in altitude, a series of changes happen rapidly and over time.

Short Term at Altitude

Within the first few hours of arrival at high altitude, a few primary effects are visible on humans as they rapidly ascend in elevation. The first and most important response seen is an increase in breathing. Breathing will increase in both depth and rate as a person ascends. Lung function, and therefore oxygen intake, is what causes problems—not the heart. As lung function is decreased, oxygen saturation declines in the blood. Lower net oxygen present causes blood oxygen saturation to decrease, which causes people at 15,000-ft elevation to have a blood oxygen saturation of 85% (versus 95% at sea level). Resting heart rate also decreases, as well as the effective cardiac output. Dehydration also sets in more easily as the body naturally attempts to increase the percentage of red blood cells in the blood, and this additional volume is removed via increased urine production. Finally, people begin to have problems with sleeping as altitude increases.

Acclimatization

As humans remain at high altitude, their body adjusts to the conditions and becomes *acclimated*. A few major changes occur. The first is an increase in respiratory volume. A person at altitude will breathe more deeply to take in as much air as possible, helping account for the decreased number of oxygen molecules in the air. The second and most critical effect of altitude is an increased number of red blood cells. Over time, this increase becomes normal, such that people who live at higher altitude have an inherently higher percentage of red blood cells in their blood. In addition to an increase in red blood cell count, at very high altitudes the third change is that blood can chemically accept more oxygen, further increasing carrying capacity. Progressively, the aerobic capacity of muscle increases and makes muscle more effective. These benefits (increased oxygen capacity and muscle metabolism potential) are why athletes train at high altitude before competing at lower altitude.

Achieving acclimatization is best done by arriving early at high altitude. Altitude sickness can be avoided by simply spending a day or two at altitude before conducting any strenuous physical activity. Some medications can mitigate the hazard that rapid ascent presents. Proper acclimation can prevent most altitude illness, but some illnesses can happen even with proper care and prevention .

Altitude Illness

Each altitude illness is fundamentally caused by the lack of sufficient oxygen and low pressure in the air. Because all of these have a similar cause, the treatment is conveniently the same.

Acute Mountain Sickness

Acute mountain sickness (AMS) is the mildest of the altitude illnesses and also the most common. The presentation is generally similar to a bad hangover and is easily treated. Generally, AMS presents with:

- Headache
- Nausea
- Vomiting (sometimes)
- Dizziness
- Fatigue
- General malaise
- Loss of appetite
- Poor sleeping

With increased altitude, the patient usually becomes dehydrated as well, causing an amplification of these symptoms. Some people present with a decrease in coordination and some cyanosis on the fingertips and lips.

High-Altitude Pulmonary Edema

High-altitude pulmonary edema (HAPE) is the buildup of fluid in the lungs and poses moderate to serious concern for those at altitude. HAPE can impact people in the high-altitude range (>11,500 ft) and presents with a generalized feeling of breathlessness and drastically decreased oxygen saturation. Pulse will generally increase, and cyanosis will appear at the fringes of the patient. Patients will present with a bubbling or crackling sound in the lungs when examined with a stethoscope.

High-Altitude Cerebral Edema

High-altitude cerebral edema (HACE) is the most serious altitude illness and is an immediate life threat to the affected person. HACE is the buildup of fluid in the brain, causing patients to present with altered level of consciousness, fever, rapid heart rate, photophobia, and potentially a loss of consciousness.

Treatment

Treatment of altitude illnesses is generally simple: descent. Descending to lower altitudes will alleviate or cure each of these altitude illnesses, helped with the administration of high-flow oxygen. Vigilant observation of team members and other people is essential to help keep everyone safe at altitude. Everyone on the rescue team needs to remain aware of the various changes and deviations from normal.

Impact on Equipment

Some items of team equipment can be susceptible to altitude. Gas detectors tend to be the most vulnerable to changes with altitude, but breathing apparatuses should also be checked.

Gas Detectors

Gas detectors require attention with changes in altitude. The sensors themselves actually measure number of particles per volume and deliver a result in percent relative to "normal." This measurement technique causes gas detection to be pressure sensitive, and the change from normal atmospheric pressure will cause the meter to read lower than is correct. For example, with a 5,000-ft change in altitude, sensors for gases other than oxygen will read approximately 17% lower than the actual reading. When a team proceeds to a new altitude (change of more than 2,000 ft), gas detectors require a complete calibration to be considered accurate. Simply zeroing the meter on startup may not properly account for the change and may cause inaccurate readings.

Oxygen sensors are not as susceptible to change in nearly the same degree as other gases, and simply zeroing the meter will correct the error present there.

Breathing Apparatus

Breathing apparatuses show no significant effects at altitude. However, it is recommended that teams check equipment before use, particularly after travel. Cold weather can impact some of the function within the unit, but inspection should determine its safety. A high-pressure leak test will verify the readiness to operate.

GEOTHERMAL CONDITIONS

At many mines around the world, geothermal conditions can present an additional hazard to teams. The addition of heat (either from the air, rock, or heated groundwater) will place teams under additional stress. All of the concerns present in hot-weather environments are also present in these conditions but can be worse.

Causes of Geothermal Conditions

Magma Related

The simplest and best identified mechanism to heat water underground is simply the presence of a magma chamber nearby. This happens near active volcanoes, as the molten rock in the ground heats the surrounding rock and groundwater. Notable examples of volcanic centers are the Yellowstone Caldera (Wyoming), the Hawaiian Hotspot, Long Valley Caldera (California), Iceland Hotspot, and along the Aleutian Islands.

Typically these areas are well known and identified, and mines in the surrounding area would have identified and mitigated the hazard. Rescue teams called to a mine in these areas should plan ahead and prepare for high temperatures underground, ensuring they have proper cooling for their breathing apparatuses.

Depth Related

With increasing depth into the earth, the temperature naturally increases. This temperature increases at a regular rate known as a *geothermal gradient*. Every location on earth is susceptible to these conditions, with some variation in areas. Scientists believe the precise cause of this geothermal gradient is due to the radioactive decay of elements deep in the earth combined with some tidal effects of the moon, heat from the accretion of the planet originally, and the crystallization of minerals.

On average, the geothermal gradient is 1°F per 70 ft of depth. This gradient tends to be accurate at a depth beneath the layers of soil and first few hundred feet of rock. Deep mines (below a 1,000-ft depth) are often known to have a heat concern at depth. Teams responding to these mines should maintain additional vigilance for a heat concern at depth.

Fluid Conduction Related

The conduction of fluid is a notable way that mines can have a locally abnormal geothermal condition. Faults provide a conduit to move hot water up from deeper (higher temperature) rock and heat from the area nearby. With the introduction of hot water to the rock, this also presents a hazard of heated (sometimes acidic) water into a mine. This heated water also adds humidity, making the mine more hazardous for miners and rescuers.

Heat from this source is more unpredictable on a regional basis. Consultation with a geologist can provide insight on any faults in the area or hazards that may exist, and consultation with the ventilation engineers at a mine can also help to answer questions about temperature. Notable mines in the United States affected by this type of heat are the underground mines in the Carlin District in northern Nevada and at the Coeur d'Alene District in Idaho. Temperatures underground can reach 120°F+ at the deeper sections of the mine.

Managing Geothermal Conditions

Once geothermal conditions have been identified, the team must be prepared and ready for abnormal heat. Team equipment should be prepared for the additional heat; clothing should not be heavy and overly insulating. Cooling ice is essential for breathing apparatuses to prevent heat injury, and proper hydration of team members is critical for their safety.

Consulting ventilation engineers is a good first step in identifying the potential hazards. Ventilation surveys and plans provide a good estimate of the issues and potential issues that may exist. If the ventilation system is functioning properly, some of the hazard should be effectively mitigated. Assessing the ventilation as the team gets deeper (both flow and temperature) is critical for teams assessing the safety of the mine at depth.

Conclusion

Mine rescue is an extremely dangerous activity, but a successful outcome can be extremely satisfying. With the knowledge gained from this text as well as what your instructors provide, you can potentially save the life of another miner.

While this text attempts to address most aspects of mine rescue, it is no substitute for hands-on training and simulations. Learn from the experience of your instructors, and feel free to ask questions. If you are unsure of exactly how something is done or uncertain about a specific scenario, ask. Continued training and learning is the key to long-term success in any rescue discipline.

Fundamental Goals of Mine Rescue

1. Ensure personal safety.
2. Ensure team safety.
3. Rescue survivors.
4. Explore and document findings.
5. Return mine to working order.

Additional Training

The following areas of instruction are suggested for obtaining further training experience.

Emergency Medical Technician

EMT training is essential for emergency medicine and trauma care at the basic life-support level. Each team should have at least one EMT as the medic position if possible, and it would be beneficial to the rest of the team for more members to be qualified. Team EMTs are certified by the National Registry of Emergency Medical Technicians (NREMT) but are licensed by the state.

Closed-Circuit Breathing Apparatus Maintenance Technician

Training from the manufacturer of the closed-circuit breathing apparatuses (CCBAs) is crucial to be effective in the operation and service of these units. Training includes bench test training, unit assembly, and troubleshooting of common or more difficult problems. Training at this level is crucial for the team technicians, and having more members trained at this level may be helpful.

Rope Rescue Technician

Training in technical rope work, including rope access, rigging ascent and descent systems, high-angle patient movement, and other rope work is essential to any team that works at a site with locations that may require high- or low-angle rope access for rescue purposes. Training should be consistent with the National Fire Protection Association (NFPA) standards for rope work and should be conducted by professionals.

Firefighter I

Teams responsible for the surface buildings, surface mine operations, or for firefighting should receive training in fire response and suppression, typically accredited as the Firefighter I certification from the NFPA. Proper training in firefighting may help with the team's response to fires above and potentially below the ground and helps with general incident management and lifesaving actions at a mine site.

Hazardous Materials Awareness

Hazardous materials (HAZMAT) awareness is designed as an introduction to rescuers on the risks of hazardous materials, recognizing these hazards, and taking basic steps to mitigate them. Any team operating where hazardous chemicals, fuels, or other compounds are present should have at least one member who had basic HAZMAT awareness training.

Confined Space Entry and Rescue

Any mine with bins, tanks, enclosed conveyors, loading hoppers, or similar structures has permit-required confined spaces. Teams responsible for responding to these locations should receive training in confined space entry and rescue of entrants and should have equipment as needed.

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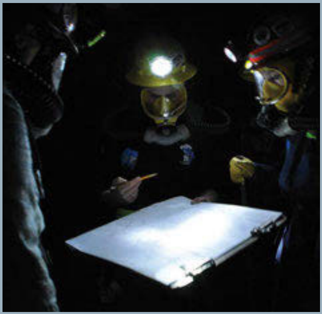
NOTE: *f.* indicates figure; *t.* indicates table

Mine Rescue Manual

A Comprehensive Guide for Mine Rescue Team Members

BY CHRIS ENRIGHT AND ROBERT L. FERRIER



Let's hope you never face a mine disaster. But if you do, you need expert help at your fingertips, and you need it NOW! Keep this book close at hand, just in case. Buy extra copies for your key management and safety staff, and make sure they read it before you need it.

With its clear descriptions, best practice benchmarks, step-by-step lists, and easy-to-follow procedural diagrams, *Mine Rescue Manual* will be your go-to guide if there's an accident at your mine. It will walk you through every contingency: properly dealing with mine fires, toxic gases, loss of oxygen, injured workers, and more. It covers how to stay in legal, regulatory, and National Incident Management System compliance when responding to and reporting an accident. An extensive section on mine recovery (and potentially resuming operation) in the aftermath is also included.

Prepared and tested at the Colorado School of Mines and published by the Society for Mining, Metallurgy & Exploration, this well-organized handbook is designed to help you respond to a mine emergency successfully, maximizing the protection of human life while minimizing the cost not only of rescue and recovery, but to your corporate reputation.

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