Ministry of Energy, Mines and Petroleum Resources

MINERAL RESOURCES DIVISION

BRITISH COLUMBIA
MINE RESCUE MANUAL

ENGINEERING AND INSPECTION
BRANCH

Province of British Columbia
Ministry of Energy, Mines and
Petroleum Resources

MINERAL RESOURCES DIVISION
Engineering and Inspection Branch

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FOREWORD

This manual is designed primarily as a text to be used in the teaching of basic rescue procedures to be used following accidents at surface and underground mining operations. It will also serve as a guide to good practices at any time when people are in a physically dangerous situation and must be moved to a safe place.

Mine rescue work is demanding and at times dangerous. Mine rescue teams are highly trained and skilled personnel. They must have an intimate knowledge of their equipment and master all the skills required to accomplish their rescue missions, although they may never be required to put their training to use. In fact, only a small percentage of miners who have received mine rescue training will ever be called upon for actual rescue work. Nevertheless, if the need should arise, rescue teams will be ready to go to the aid of their fellow workers.

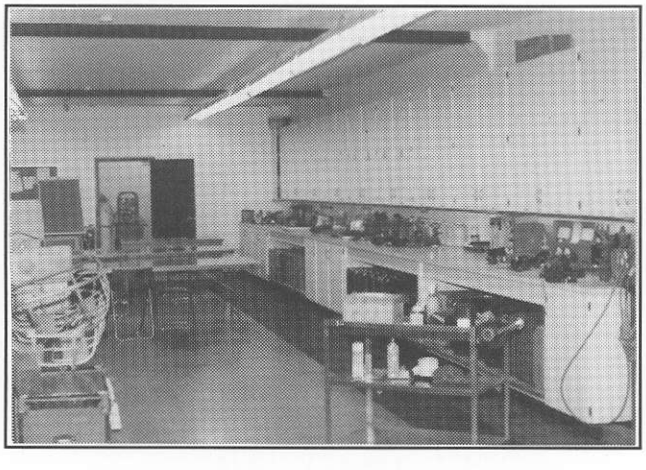
It is also most important that mine officials receive periodic instruction and training in the duties they will be required to perform, both individually and collectively, in the event of a mine disaster at their operation.

The mining laws of British Columbia require that trained mine rescue personnel and mine rescue equipment be maintained at all mines. To this end, basic mine rescue training courses are conducted at mining properties so that miners will have an opportunity to learn the skills required of the mine rescue team. Once the basic skills are learned, many hours of training and practice are needed to develop a competent mine rescue team that can work together and, with other teams, accomplish rescue objectives in the event of a mine disaster.

On several recent occasions British Columbia mine rescue teams have been called upon to assist in disasters both in the province and in other areas. It is a tribute to the skill, training and courage of these men that they have always done their job in an exemplary way which has brought praise and recognition for their efforts.

The Mine Rescue Certificate and the "MINE RESCUE" sticker on your hard hat are things to be proud of as they tell the world that you are concerned and that you really care about your fellow workers. You care to the extent that you have been willing to devote many hours of study and practice to learn the skills required of a mine rescue team.

Ralph W. McGinn,
Chief Inspector of Mines,
Ministry of Energy, Mines and
Petroleum Resources.



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[1] Survival Course, O_2, CO, NO_2, H_2S, SO_2, CO_2, CH_4, H_2 only.

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CHAPTER 1

INTRODUCTION

This manual is designed to provide basic training in the rescue procedures to be followed in the event of an accident at a surface or underground mining operation. The mining laws of British Columbia require that trained, properly equipped mine rescue teams be maintained at all mining operations, both surface and underground. To this end, the province provides basic mine rescue training courses at mining properties so that miners will have an opportunity to learn the skills demanded of a mine rescue team.

FUNDAMENTAL PRINCIPLES OF MINE RESCUE TRAINING

The fundamental principles of mine rescue training are, in order of importance:

- Ensuring the safety of the rescue team.
- Endeavouring to rescue or ensuring the safety of trapped or injured workers.
- Protection of the mine property from further damage.
- Rehabilitation of the affected work area and salvage of equipment.

Through training, mine rescue teams will become familiar with:

- Mine rescue equipment.
- Mining equipment that may be useful in an emergency (cranes, loaders, scooptrams, etc.).
- Hazards involved in mine rescue work (toxic and flammable gases, electricity, rock-falls, etc.).

Although mine disasters are a rare occurrence, and many trained mine rescue workers will never be called upon to exercise their skills, every year there are several dangerous or unusual incidents in British Columbia mines, many of which require the assistance of trained mine rescue personnel. The most commonly reported dangerous occurrences involve fire, machinery or electrical equipment.

REQUIREMENTS FOR MINE RESCUE TRAINING

Mine rescue work is physically and mentally demanding, and at times dangerous. Members of mine rescue teams must not only have an intimate knowledge of their equipment but must also be physically sound and fit to perform strenuous work while wearing breathing apparatus, and have good judgement and a cool, calm temperament. They should be selected carefully and must receive thorough training and instruction in rescue and recovery procedures, and the use and care of breathing apparatus. Frequent additional training and instruction should be given in an irrespirable atmosphere, to ensure that both crew and equipment are in condition to meet an emergency. Training exercises involving a recovery problem should be conducted occasionally. Many hours of training and practice are needed to develop a competent mine rescue team that can work effectively with other teams to accomplish rescue objectives in the event of a mine disaster.

It is also most important that mine officials receive periodic instruction and training in the duties they must perform, both individually and collectively, should a fire, explosion or other disaster occur at their mine. They must be informed where tools, equipment and materials can be obtained quickly, both on the mine and from outside sources. All supervisory staff should be instructed that, in the absence of higher authority, they must take charge, act on matters requiring immediate attention, and notify all persons required to assist at a disaster, particularly the District Mine Inspector having charge of the district in which the mine is located, the mine rescue team, and any other help that may be available.

MINIMUM QUALIFICATIONS

Candidates for mine rescue training must meet the following minimum requirements:

- Minimum age of 18 years.
- Speak, read and write English.
- Be in good physical and mental condition (*see* Medical Requirements below).
- Be familiar with mining conditions, practices, hazards and equipment.
- Have no perforated eardrums (tympanic membrane).
- Hold a valid St. John's Ambulance Standard First Aid Certificate or its equivalent.
- Hold a Survival Mine Rescue Certificate (if employed in underground mining).
- Have facial hair shaved to the point it does not interfere with the seal on breathing apparatus.

Whether a candidate for undergound mine rescue, surface mine rescue or first aid training, the applicant must be mentally and physically capable and prepared to render assistance whenever called upon to do so.

MEDICAL REQUIREMENTS

Candidates for mine rescue training must pass a physical and medical examination (*see* Ministry of Energy, Mines and Petroleum Resources Medical Examination for Mine Rescue Training; Appendix 1-1), or produce a current Certificate of Fitness as prescribed by the British Columbia Workers' Compensation Board (*see* Forms 12 and 13, Appendix 1-2).

MINE RESCUE CERTIFICATION

The Basic Underground or Surface Mine Rescue Certificate (Appendix 1-3) will be issued to candidates who successfully complete the training course. If a candidate has passed the written and oral examinations, but is unable to qualify for the basic certificate due to inability to produce a current medical certificate or Certificate of Fitness, or physical or psychological inability to complete the practical requirements of the course, a "theory only" seal (Appendix 1-4) will be attached to the certificate.

ACKNOWLEDGMENTS

This Mine Rescue Manual has evolved from the integration of revised editions of the General Underground Mine Rescue Manual (B.C. Ministry of Energy, Mines and Petroleum Resources, Paper 1977-2) and the Surface Mine Rescue Manual (B.C. Ministry of Energy, Mines and Petroleum Resources, Paper 1981-4).

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CHAPTER 2

MINE RESCUE OPERATIONS

EMOTIONAL STRESS IN ACCIDENT SITUATIONS

An accident may cause many different reactions from individuals, all quite normal, but some sufficiently severe that the victims will need help. Everyone involved will be stunned and temporarily disoriented, but most will probably adapt themselves quickly and respond positively to the demands of the situation.

Frequently, victims will require more than rescue because they may be so emotionally overwhelmed that their reactions become exaggerated and dangerous to themselves or others. Family anxiety is natural and time given to needed support may prevent persons from collapsing from shock, family members from injuring themselves, or hysteria from spreading to crowds.

Rescuers bring their own special reactions, values and capabilities with them. They will always be affected by the stressful situations under which they work, but their reactions must not affect their ability to perform effectively.

DECISION MAKING

Making the decisions required for a successful rescue operation is the same as making the decisions in other areas of your life. The problem is defined, an objective is set, facts are gathered, the facts are analysed using knowledge and experience, alternative solutions are considered, a course of action is chosen and implemented, and the results are evaluated. If the chosen solution turns out to be unsatisfactory, another alternative is chosen to replace it.

The human mind, however, does not work in such a linear way, which is why many decisions can be made quickly. The reason the process is outlined here as a linear progression is to remind the person that may find himself in charge of a rescue operation that decisions at an emergency scene should not be made too quickly, and the impulse to act immediately must be tempered with reason. When rational thought is abandoned, irrational decisions are likely to be made that will allow the situation to get out of control.

The process of rational decision making at the scene of an emergency can be summarized as:

- Identify the problem.
- Form an objective based on known information and resources.
- Select one or more alternatives from the available options.
- Take appropriate action.
- Analyse results.

PERSONAL SAFETY AND PROTECTIVE CLOTHING

The environment in which mine rescue teams perform their duties demands that they be provided with the best personal protective equipment available. Injuries can be reduced if crew members have adequate protective clothing and breathing apparatus at their disposal and use them when needed. The provision and use of quality protective equipment will not, by themselves, assure individual safety. All protective equipment has limitations that must be recognized so that users will not overextend its range of protection. Extensive training in the use and maintenance of protective equipment is essential to assure that it will provide optimum protection.

A variety of protective gear may be necessary to provide the protection needed in the many different situations that may be encountered by the rescue team. All members should be aware of the type of equipment needed for different situations and know where this equipment is readily available (Figure 2-1).

Figure 2-1. Mine rescue personnel must be aware of the degree of protection afforded by all protective equipment, and its limitations.

HAND PROTECTION

The selection of hand protection should reflect the tasks being performed. When initiating rescue work, consideration should be given to the need for cut and abrasion-resistant gloves, electrical hot gloves or chemical-resistant gloves.

FOOT PROTECTION

As rescue workers may be required to be on their feet for long periods, boots should be well fitted, comfortable and provide ankle support.

EYE PROTECTION

As for most other personal protective equipment, the selection of eye-wear must reflect the task in hand and the conditions at the scene of the accident. Adequate protective eye-wear includes safety glasses (with side shields), goggles, face shields and tinted glasses or shields.

OTHER PERSONAL PROTECTIVE EQUIPMENT

Every accident situation will present its own unique hazards. Rescue workers should be aware of the hazards and be familiar with the equipment or clothing, such as turnout gear, hard hats or helmets, respiratory protection (breathing apparatus), chainsaw chaps and other items that are available to protect against them.

WORKPLACE HAZARDOUS MATERIALS INFORMATION SYSTEMS (WHMIS)

Mine rescue workers must have access to the Material Safety Data Sheet for all products used on their property and, when evaluating an accident scene, must determine if there are controlled products present and whether or not they pose a hazard to the injured or to rescue workers.

Use of the Material Safety Data Sheet will help determine how to control a fire, protect workers and contain a spill or leak.

THE MINE RESCUE TEAM

In British Columbia, a full mine rescue team consists of six people. Each must hold a valid mine rescue certificate, be in good physical condition with a current Certificate of Fitness and should have had recent practice with rescue breathing apparatus.

Six qualified people do not, however, make a mine rescue team unless they practise regularly and drill as a team. It is only through regular practice together that they learn to work effectively as a team and that each individual will develop the confidence he must have in his fellow team members.

Working together is important in any team effort, but in mine rescue work the life of every member of the team is dependent on the actions of each of the others. If a basketball or hockey team does not work well together they will probably lose a game, but if a mine rescue team does not work together effectively then their very existence is at stake. The importance of cooperation and teamwork by the members of a mine rescue team cannot be overemphasized.

THE TEAM CAPTAIN

One member of the mine rescue team will be the team captain and will direct the actions of the team at all times.

As the general safety and operation of the team and the rescue work to be carried out are under the supervision and direction of the captain, the qualifications of a team captain are very demanding.

The team captain must have an excellent knowledge of mine gases. He must know the physiological effects of the gases, their explosive range and flammability, the relative weight and sources of gases, how to test for them and how to treat persons affected by them. Many of the decisions made by a mine rescue captain during search and rescue work are dependent to a great extent upon the gaseous conditions in the mine; unless he has an intimate knowledge of gases the captain cannot make intelligent decisions.

One of the most important factors affecting the safety of mine rescue personnel and workers trapped in mines is mine ventilation. Although in actual disaster work the major decisions with respect to firefighting and re-establishing mine ventilation will be made by the disaster coordinator, the mine rescue team captain must also have a good knowledge of this subject.

The mine rescue team's travel through the mine is affected by the ventilation existing at the time and actions taken by the team will affect ventilation. The team captain's knowledge of ventilation must be such that he can make correct on-site decisions that do not endanger his team or others in the mine.

The team captain must know how to use the various instruments required for measuring air flows and air pressures in mine workings and he must be able to make basic interpretations of such readings. He must know if he should open a door or close it, what affects a seal on a fire will have on air flows and what affect the fire will have if it is not sealed. He must, in other words, have an excellent basic understanding of the factors that affect air flows in mine workings.

The mine rescue team captain must know how to fight fires, how to erect mine timber and how to build fire stoppings; he must be able to quickly assess hazards; he must know how to treat injured men and how to transport them. He must have a good practical knowledge of mining.

The team captain has others on his team, some of whom may have more detailed knowledge of some subjects than he has, but he must be able to make the decisions and direct the work of the team.

The most important quality required of a mine rescue team captain is "Leadership". He must have the confidence and respect of his team members. He must be calm and cool headed, and be able to think clearly under pressure. He must be able to instill a strong feeling of team spirit. Each member of a team must have the utmost confidence in the captain and should follow orders explicitly.

The mine rescue team captain is No. 1 man on the team and must, first and foremost, be a competent leader. He is in charge and directs all actions of the team.

THE VICE-CAPTAIN

The vice-captain of a mine rescue team is the No. 5 man. In the event that something should happen to the captain, the vice-captain must take control of the team and therefore must have similar qualifications to those of the captain.

When a mine rescue team travels through a mine, it is led by the captain and the vice-captain generally brings up the rear. One of the vice-captain's main functions while traveling is to keep an eye on all members of the team and to warn the captain should any member show signs of distress. The vice-captain is a second pair of eyes for the captain and, in addition to watching the team members, he will keep a sharp lookout for any condition missed by the captain. He should keep in mind that the captain has a heavy responsibility and that his mind is occupied by many matters and he may not notice all the details that the vice-captain is aware of. The captain should be advised by his vice-captain if it appears that a significant factor has been overlooked.

The actual distribution of jobs among team members may vary from team to team, however, it is very common practice to have the vice-captain assist the captain in gas and ventilation tests. He also makes close checks of team members during rests and does what he can to relieve the captain of routine duties so that he can devote his efforts to the heavy responsibility which he carries.

NUMBERS 2, 3 AND 4 TEAM MEMBERS

Various other duties are distributed among the other team members. One member usually has special expertise in first aid and will carry out most of the first aid work required. Another may be assigned to fighting small fires and will have extra training in the use of fire extinguishers. Someone will probably be more competent in mine timbering work and someone will have special electrical, mechanical, surveying and mining knowledge.

As mine rescue teams are being assembled, consideration must be given to the special skills that may be required and team members should be chosen with these factors in mind. These skills will vary from mine to mine.

The No. 2, No. 3 and No. 4 members have the various skills that may be required of the team. They work under the direction of the captain to accomplish the objectives of the team.

The No. 6 member is the coordinator, the liaison person between the team captain and the overall coordination centre. He is stationed at the fresh-air base and must be in constant communication with the captain and the surface control. He is responsible for the operation of the base.

COMMUNICATION BY TEAM MEMBERS

All members of a mine rescue team must observe strict discipline and must obey all directions given to them by the team captain without question.

Most modern mine rescue breathing apparatus is equipped with a speaking diaphragm which makes limited voice communication possible between members of the team. Circumstances can arise in the mine when voice communication is not possible and many team captains find that better discipline is achieved if voice communication is kept to a minimum at all times. In order to assure that good communication is always possible, a standard set of horn, bell or whistle signals has been adopted in British Columbia.

The captain and the vice-captain will both carry a horn, bell, whistle or whatever is used for signaling and, although most signals will be given by the captain, it may be necessary for the vice-captain to signal from time to time.

The standard code of signals adopted in British Columbia is as follows:

One — To advance if stopped or at rest; to stop if in motion.

Two — To rest.

Three — Distress: this signal will often be given by the vice-captain as he is observing the team members during travel and will be first to notice signs of distress.

Four — Attention: at this signal all team members will look at the person giving the signal and receive further instructions.

Five — Retreat: at this signal the team will immediately retreat in the direction from which they have just come. The vice-captain may lead the team in retreat for short distances through areas already explored, but should not lead the team into unexplored areas. As soon as circumstances permit, the captain should resume the responsibility of leading the team.

Hand signals are not standardized but are worked out by each team to best suit their operating techniques. The proper use of hand signals is another reason why teams must practise regularly. All team members must know the team's hand signals so that they can be quickly acted upon and so that there will be no confusion as to what is required.

TEAM DISCIPLINE

It is of the utmost importance that the mine rescue team be well trained in the use and care of their apparatus. They must be efficient in performing the various duties they will be called upon to do. Their morale must be of the highest, such as only constant training and expert knowledge of their apparatus will provide.

TEAM SAFETY

The safety of the team is of primary importance and is the first consideration of mine rescue. The captain must keep his team's safety foremost in mind at all times.

It is, of course, understood that any team entering a mine after an explosion, or to fight a mine fire, is taking a calculated risk. The captain will receive instructions from the control centre, but must give each situation careful thought before proceeding, and must keep the odds in favour of his team at all times. The captain should advance his team through the mine cautiously, paying particular attention to the roof and walls and to the condition of the mine atmosphere, and recording this information.

The team must be rested regularly and be constantly observed for signs of distress in any member. Work must be distributed as evenly as possible among all members.

THE FRESH-AIR BASE

A fresh-air base is, as the name implies, a base at which good respirable air has been established. It is the point of departure for the mine rescue team and no one should proceed beyond the fresh-air base unless they have respiratory protection apparatus with them.

The fresh-air base must have an assured supply of good air at all times. In choosing the base, consideration should be given to providing the following:

- A clean area with good lighting.
- An assembly area for servicing breathing apparatus.
- An area for briefing and debriefing mine rescue teams.

If the base is located underground, consideration should also be given to the following points:

- The travelway from the base to surface must always be assured of good air.
- Underground to surface communication.
- Necessary tools and supplies to carry out the work at hand.
- First aid equipment and supplies.

Although some breathing apparatus on the market today may be recharged for a factory approval rating of 3 hours (Aerorlox) or 4 hours (B.G. 174), the British Columbia Ministry of Energy, Mines and Petroleum Resources adheres to a policy whereby no person will work for more than 2 hours while wearing breathing apparatus. Teams will therefore follow the general rule of allowing twice as much time or twice the amount of oxygen to travel out as they used to travel in.

ROUTE OF TRAVEL

It is fundamental that a rescue team should explore a mine via the fresh-air route wherever possible. There are two good reasons for this practice:

- The risk to an exploring team is lessened.
- The fresh-air base can be located nearer to the scene of action.

Circumstances prevailing may make it impossible to travel by a fresh-air route, but the team captain must always be sure that he has a safe route of retreat for his team and must not chance having his team "cut off" from a means of retreat.

The route of travel must always be properly marked by an advancing mine rescue team. The two principal reasons why this is done are:

- So that the team can retrace its steps on the way out of the mine. Under conditions of poor visibility or in complicated mine workings, it is not difficult to lose one's way. Marking the travel route will prevent the team from becoming lost.
- If the team should get into trouble and cannot get out of the mine, a team coming to their assistance can find them by following their route markers.

The travel route is marked by either trailing a communication line or by marking the route with chalk or paint at key points along the way. If chalk or paint are used, an arrow should be marked on the walls at key points, pointing in the direction from which the team has come. If the team should retrace their steps, route markers should be cancelled. The details of the method of route marking must be understood by all backup teams.

All team members must remain in visual contact with one another at all times and, if this is not possible due to poor visibility, they must keep in physical contact by using lifelines or by some other means such as holding hands or carrying a stretcher. Team members must never become separated.

Extreme caution must be used when traveling under conditions of poor visibility as any hazard is compounded if it cannot be seen.

When any work is being done by the team, such as building stoppings, timbering, barring, etc., the captain or vice-captain must keep a constant watch to be certain that team members are not exposed to danger and work should be distributed as evenly as possible among the team members so that no individual becomes undnly fatigued.

RESCUE PROCEDURES

TESTING THE MINE ATMOSPHERE

One of the most important considerations in mine rescue and recovery work is the condition of the mine atmosphere. The captain, possibly with the vice-captain's assistance, makes all gas tests and keeps a detailed record of the conditions encountered. All team members should be kept informed of the condition of the atmosphere.

In addition to checking the atmosphere, the amount and direction of air movement must be noted and nothing must be done to change ventilation until the results are known.

STRETCHER PROCEDURE

When exploring a mine the supplies and tools used by the team are usually carried on a stretcher. The stretcher is then, of course, available for transporting casualties.

Wherever the width and condition of the roadway permit, the Nos. 2, 3, 4 and 5 team members should share the weight of the stretcher. Rests should be taken frequently and team members allowed to change hands on the stretcher. At times, of course, only two men may be able to carry the stretcher. Under these circumstances more frequent rests will be required and the crew should spell one another off.

CARE OF CASUALTIES FOUND IN THE MINE

When injured workers are found in the mine they must be properly treated and given the necessary respiratory protection. If they are found in a dangerous atmosphere, breathing apparatus should be supplied to them and, if possible, they should be moved to an area of good air. They should be taken to the fresh-air base if it is safe to do so, or they should be isolated in an area where there will be the minimum possible exposure to dangerous gases. Refuge stations may be used for this or it may be necessary to seal men in temporary refuge stations.

The mine rescue team must be certain that the injured know how to use any breathing apparatus supplied and, if it becomes necessary to leave them temporarily, they must be assured that they will be safe and that they must remain in one place. What is done with casualties will depend on prevailing conditions, but they must not be exposed to further danger and they must understand that they will be looked after. Proper first aid procedures must be followed for all injuries.

All miners found should be identified and their locations indicated on mine plans. If dead bodies are found they must be identified and left in the mine until the living are taken care of.

It may be necessary to physically restrain irrational victims to prevent them from injuring themselves. Persons who are not irrational should never be tied up or otherwise restrained.

When accident victims are being brought from the mine they should be closely watched and prevented from "bolting" as fresh air is neared. Persons being rescued should always travel between rescue team members.

THE MINE RESCUE UNIT

The mine rescue unit consists of a **minimum** of three mine rescue teams summoned to a mine disaster; if the operation extends beyond 6 to 8 hours, additional teams must be called in. In order to reduce fatigue, the teams are rotated to allow one team at work, one team on hand as backup and the third team at rest. A typical rotation for a three-team unit is as follows:

Team Working (max. 2 hrs.)	**Back-up Team**	**Team at Rest**
A-team	B-team	C-team
B-team	C-team	A-team
C-team	A-team	B-team

Teams have approximately 6 hours rest prior to working for 2 hours. *See* Figure 2-2 for a six-team arrangement.

Date

Team No.	Description	Time											
1.		Active				Reserve	Stand-by at F.A.B.	Active				Reserve	Stand-by at F.A.B.
2.		Stand-by at F.A.B.	Active				Reserve	Stand-by at F.A.B.	Active				Reserve
3.		Reserve	Stand-by at F.A.B.	Active				Reserve	Stand-by at F.A.B.	Active			
4.			Reserve	Stand-by at F.A.B.	Active				Reserve	Stand-by at F.A.B.	Active		
5.				Reserve	Stand-by at F.A.B.	Active				Reserve	Stand-by at F.A.B.	Active	
6.					Reserve	Stand-by at F.A.B.	Active				Reserve	Stand-by at F.A.B.	Active

Signed

Figure 2-2. Rotation of mine rescue teams in event of fire underground – six-team arrangement. This arrangement allows for each team to have 6 hours on duty (2 hours active; 2 hours on stand-by at the fresh-air base; 2 hours in reserve) followed by 6 hours complete rest in each rotation. If indications are that the operation will be extensive a nine-team rotation (Figure 2-3) is advisable and new teams should be added as soon as they become available.

Date

Team No.	Description	Time											
1.		Active							Reserve	Stand-by at F.A.B.	Active		
2.		Stand-by at F.A.B.	Active							Reserve	Stand-by at F.A.B.	Active	
3.		Reserve	Stand-by at F.A.B.	Active							Reserve	Stand-by at F.A.B.	Active
4.			Reserve	Stand-by at F.A.B.	Active							Reserve	Stand-by at F.A.B.
5.				Reserve	Stand-by at F.A.B.	Active							
6.					Reserve	Stand-by at F.A.B.	Active						
7.						Reserve	Stand-by at F.A.B.	Active					
8.							Reserve	Stand-by at F.A.B.	Active				
9.								Reserve	Stand-by at F.A.B.	Active			

Signed

Figure 2-3. Rotation of mine rescue teams in event of fire underground – nine-team arrangement. This arrangement allows for each team to have 6 hours on duty (as in Figure 2-2) followed by 12 hours complete rest in each rotation.

CHAPTER 3

MINE GASES - RECOGNITION, EFFECTS AND TREATMENT

TRAINING OBJECTIVES

The objectives of the following discussion of mine gases is to ensure the trainee understands:

(1) Mine regulations relating to exposure to mine gases.

(2) The terms:

- Threshold limit value.
- Short-term exposure.
- Time-weighted average.
- Physical and chemical properties of gases.

(3) The properties and effects of:

- Acetylene.
- Air.
- Ammonia.
- Carbon dioxide.
- Carbon monoxide.
- Chlorine.
- Hydrogen.
- Hydrogen cyanide.
- Hydrogen sulphide.
- MAPP.
- Methane.
- Nitrogen.
- Oxides of nitrogen.
- Oxygen.
- Powder smoke.
- Propane.
- Sulphur dioxide.
- Gases given off from burning rubber.

INTRODUCTION

Many gases found in a mine during normal operating conditions can have a harmful effect on the human body if breathed for a period of time in concentrations above the recognized safe limit for the time period. During a fire in an underground mine, large quantities of deadly gases may be given off. The biggest problem confronting the miner at the time of a mine fire is to protect himself from these gases.

ON THE THRESHOLD OF UNDERSTANDING - TOXIC CHEMICALS

Deadly concentrations of toxic gases may be only a few parts per million (ppm). For many of us, 1 ppm is about as hard to visualize as the national debt. The following examples will help you to grasp what one part per million really represents and also help you think in metric units. One ppm is the same as:

- 1 ounce of sand in 31 tons or 1 gram per tonne.
- 1 inch in 16 miles or 1 centimetre per kilometre.
- 1 minute in 1.9 years.
- 1 ounce of dye in 6240 gallons of water or 1 gram per 1000 litres.
- 1 square inch in 1/6 acre or 1 square centimetre in 100 square metres.
- 1 cent in $10 000.

Keep these comparisons handy; they may sharpen your sense of threshold limit values.

THRESHOLD LIMIT VALUES

Threshold limit values refer to airborne concentrations of substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse effect. Because of wide variation in individual susceptibility, however, a small percentage of workers may experience discomfort from some substances at concentrations at or below the threshold limit; a smaller percentage may be affected more seriously by aggravation of a pre-existing condition or by development of an occupational illness.

Definitions. Three categories of Threshold Limit Values (TLVs) are specified, as follows:

(a) The *Threshold Limit Value–Time Weighted Average (TLV-TWA)* — the time-weighted average concentration for a normal 8-hour workday and a 40-hour workweek, to which nearly all workers may be repeatedly exposed, day after day, without adverse effect.

(b) *Threshold Limit Value–Short Term Exposure Limit (TLV-STEL)* — the concentration to which workers can be exposed continuously for a short period of time without suffering from (1) irritation, (2) chronic or irreversible tissue damage, or (3) narcosis of sufficient degree to increase the likelihood of accidental injury, impair self-rescue or materially reduce work efficiency, and provided that the daily TLV-TWA is not exceeded. It is not a separate independent exposure limit, rather it supplements the time-weighted average (TWA) limit where there are recognized acute effects from a substance whose toxic effects are primarily of a chronic nature. STELs are recommended only where toxic effects have been reported from high short-term exposures in either humans or animals.

A STEL is defined as a 15-minute time-weighted average exposure which should not be exceeded at any time during a work day even if the 8-hour time-weighted average is within the TLV. Exposures at the STEL should not be longer than 15 minutes and should not be repeated more than four times per day. There should be at least 60 minutes between successive exposures at the STEL. An averaging period other than 15 minutes may be recommended when this is warranted by observed biological effects.

(c) *Threshold Limit Value-Ceiling (TLV-C)* — the concentration that should not be exceeded during any part of the working exposure.

Airborne particulate concentrations are generally measured in milligrams per cubic metre of air (mg/m^3) and gaseous concentrations are measured as parts per million or per cent by volume.

HAZARDS DURING AND AFTER FIRES

During and following fires the two greatest hazards to life are poisoning from the breathing of carbon monoxide and suffocation in an atmosphere deficient in oxygen. The conditions which cause contamination of mine atmospheres are as follows, listed in order of the seriousness of the hazard:

CARBON MONOXIDE – This gas is always present at the time of a fire and gives little or no warning of its presence.

OXYGEN DEFICIENCY – This condition occurs because of the consumption of oxygen by combustion or chemical reaction and its replacement by toxic or inert gases. Precautions must always be taken against it.

SMOKE – The hazard is due to its irritating qualities and obstruction of vision. It may be explosive.

EXPLOSIVE GASES – Gases generated by fire (as in smoke) may explode.

METHANE – This gas is not produced by mine fires or explosions but may cause them. Its presence in a mine during rescue or recovery operations creates a major hazard.

SULPHUR DIOXIDE – This gas is present when a fire occurs in a sulphide orebody. Because of its irritating qualities it gives advance warning when in low concentrations.

OTHER GASES – Hydrogen sulphide, nitrous oxides, etc., are not likely to be encountered but the possibility of their occurrence should be kept in mind. Hydrogen sulphide sometimes indicates the presence of methane.

BURNING CONVEYOR BELTS AND RUBBER TIRES

In fires caused in conveyor belting by frictional heating, the cotton carcass is usually the first thing ignited, but once the belting is burning the flames spread along the rubber cover. Materials in addition to the belting (in metal mines this could be grease and oil) are likely to support the burning of the belt.

Polyvinylchloride (PVC) covered belting is practically nonflammable, but, when heated, both PVC and neoprene (found in rubber tires) give off chlorine gas. PVC contains 55 per cent by weight of chlorine. Synthetic rubber and neoprene contain about 40 per cent chlorine.

The products of decomposition and burning of conveyor belting and rubber tires are many and complex. The gases produced are listed in Table 3-1 and, to indicate the danger of some of these gases, the maximum allowable concentrations permitted are shown. Carbon monoxide is actually one of the least poisonous.

TABLE 3-1
GASES PRODUCED BY BURNING RUBBER, NEOPRENE AND PVC

	Maximum Allowable Concentration	
	ppm	**per cent**
Carbon monoxide	50	0.005
Chlorine	1	0.0001
Hydrogen chloride	5	0.0005
Phosgene*	0.1	0.00001
Sulphur dioxide	2	0.0002
Hydrogen sulphide	10	0.001
Nitrogen dioxide	3	0.0003
Ammonia	50	0.005
Hydrogen cyanide	10	0.001
Arsine*	0.05	0.000005
Phosphine*	0.3	0.00003

* Note the toxicity of these gases as compared to carbon monoxide.

From "Investigations into Underground Fires", *Safety in Mines Research Establishment*, Buxton, England.

MINE GASES, THEIR OCCURRENCE, PROPERTIES, EFFECTS ON HUMAN BEINGS AND TREATMENT OF AFFECTED PERSONS (Table 3-10)

ACETYLENE (C_2H_2)

Acetylene is a highly flammable hydrocarbon fuel which, with oxygen in the oxyacetylene process, produces industry's hottest flame (3260°C; 5900°F). Acetylene is very unstable and can become dangerously explosive if compressed above 100 kilopascals (kPa) (15 psi) in the free state. Acetylene cylinders are therefore packed with porous material that is saturated with acetone in which the acetylene is dissolved. Acetylene can thus be safely stored and transported at a pressure of 1700 kilopascals (250 psi). Never use acetylene above 100 kilopascals (15 psi), it is hazardous and against the regulations. Acetylene forms an explosive compound with copper and alloys containing more than 67 per cent copper. The hazard is carefully avoided in the manufacture of welding torches, tips and regulators. A word of warning, some welders call acetylene "gas" and oxygen "air". This dangerous habit could cause death or injury under certain circumstances. Call acetylene by its proper name and other gases by their names.

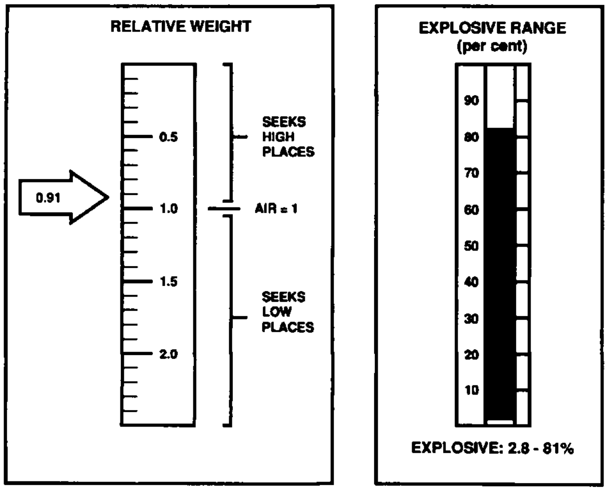
The properties of acetylene are summarized in Figure 3-1.

AIR

Air is the invisible envelope surrounding the earth, in which plants, animals and human beings live and breathe. It is a mixture of several gases which, though ordinarily invisible, can be weighed, compressed to a liquid or frozen to a solid.

Pure, dry air at sea level contains several gases, in the following proportions by volume per cent: oxygen (O_2), 20.94; nitrogen (N_2), 78.09; carbon dioxide (CO_2), 0.03; and argon (Ar), 0.94. Traces of other gases, such as hydrogen

ACETYLENE (C_2H_2)



PROPERTIES
COLOUR: None.
ODOUR: Distinct odour.
TASTE: None.
OTHER: Displaces oxygen; pressure sensitive above 100 kPa.

HOW FORMED
Action of water on calcium carbide.

THRESHOLD LIMIT VALUE AND EFFECT ON HUMANS
Acetylene displaces oxygen in the air. High concentrations will therefore result in symptoms of oxygen deficiency

TREATMENT OF AFFECTED PERSONS
Ventilation. Remove to fresh air if unconscious. Give oxygen and artificial ventilation as required.

Figure 3-1. Acetylene – key characteristics.

and helium, are also present. The air in a well-ventilated mine seldom shows any depletion of the oxygen content.

Mine air may be contaminated by the presence of other gases such as carbon monoxide, sulphur dioxide, hydrogen sulphide, methane, oxides of nitrogen and excess carbon dioxide. The presence of these gases may be due to any of the following:

- After-effects of blasting or other explosions.
- After-effects of mine fires.
- Diffusion from ore or country rock, as with methane.
- Decay of mine timber.
- Absorption of oxygen by water or oxidation of timber or ore.
- Use of diesel motors underground.
- Gas released from thermal water – carbon dioxide, hydrogen sulphide.

Except in the case of fire, adequate positive ventilating currents will prevent any dangerous accumulation of these gases. Gases may affect people either by their combustible, explosive or toxic qualities, or, if inert, by the displacement of oxygen. The effects may be due to a variety of conditions including:

ALTITUDE – Breathing becomes more laborious due to the decrease in oxygen content as the altitude increases. This is not dangerous unless conditions are extreme or the work arduous.

HUMIDITY – High temperatures with high humidity are very enervating and cause considerable discomfort.

TEMPERATURE – High temperatures with low humidity are not dangerous except from the blistering effect of heat.

IMPURE AIR:

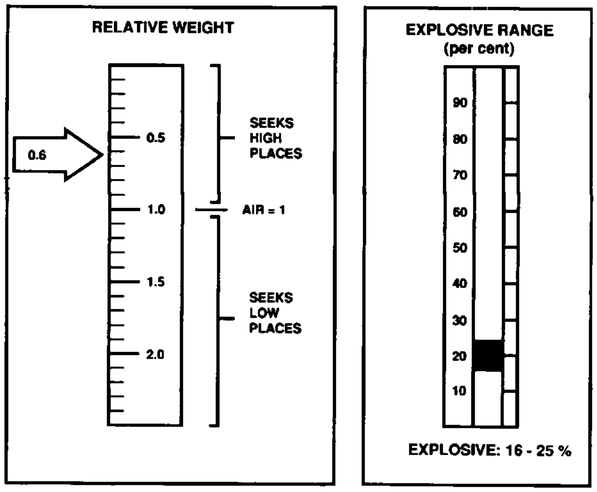
- Nontoxic gaseous impurities are not dangerous unless they have displaced oxygen to a level below 16 per cent.
- Regardless of the oxygen level, some toxic gases have deadly effects, even in very low concentrations. Effects may be sudden or gradual, depending on the concentration of the impurity.

AMMONIA (NH_3)

Ammonia (also known as anhydrous ammonia or ammoniac) is a colourless gas with a strong and distinctive smell detectable at concentrations of 1 to 50 ppm. It is formed by the reaction of nitrogen with hydrogen in the presence of a catalyst and has a number of industrial uses. It is stored in commercial cylinders as a compressed liquefied gas. It is corrosive and also explosive when exposed to heat and oxidizing substances. Its key characteristics are summarized in Figure 3-2.

Ammonia is not a strongly toxic gas, indeed in Victorian times ladies sometimes carried a small bottle of ammonia solution and inhaled the fumes as a remedy for fainting

AMMONIA (NH_3)



PROPERTIES
COLOUR: None.
ODOUR: Strong.
TASTE:
OTHER: Caustic. Explosive range 16 - 25% when exposed to heat and oxidising substances.

HOW FORMED
Combination of hydrogen and nitrogen with catalytic action.

THRESHOLD LIMIT VALUE AND EFFECT ON HUMANS
25 ppm for 8 hours or 16 ppm for 12 hours. Corrosive irritant to eyes, ears, nose and lungs.

TREATMENT OF AFFECTED PERSONS
Remove to fresh air. Rest.

Figure 3-2. Ammonia – key characteristics.

attacks. However, its corrosive qualities will irritate the eyes, nose, throat and lungs and may cause considerable distress. Discomfort will be felt at concentrations of 20 to 25 ppm and exposure to an atmosphere containing 130 ppm ammonia for 5 minutes will cause nose and throat irritation. At concentrations of 400 to 700 ppm irritation of the eyes, nose and throat will be severe. Even brief exposure to concentrations of 5000 ppm or more may cause rapid death due to suffocation or fluid in the lungs.

FIRST AID PROCEDURES

- **Ammonia Inhalation:** Remove the source of the ammonia or move the victim to fresh air. If breathing has stopped, summon medical help and begin artificial respiration or cardiopulmonary resuscitation immediately.
- **Eye Contact:** Summon medical help immediately and flush out contaminated eyes without delay, using lukewarm, gently flowing water for 20 minutes, by the clock, and holding the eyelids open.
- **Skin Contact:** In the event of skin contact with liquid anhydrous ammonia, flush the contaminated areas with lukewarm, gently running water for at least 20 minutes. Under the running water, carefully out around clothing that sticks to damaged skin and remove the rest of the garment. Obtain medical help immediately. Permanently discard all contaminated clothing, including shoes and other leatherware.

SPILL PROCEDURES

In the event of a spill or leak of liquid ammonia, restrict access to the area until clean-up is completed. Extinguish or remove all possible sources of ignition. Ensure that clean-up is done by trained personnel wearing adequate personal protective equipment. Ventilate the area and notify the appropriate government environmental agencies if the spill has not been fully contained.

Clean-up procedures are:

- Move the leaking cylinder to an exhaust hood or safe outdoor area for venting. Mark the empty cylinder DEFECTIVE.
- Use a water spray or fog to reduce the gas cloud from a serious leak or spill, but do not aim a water jet directly at the source of the leak.
- If possible, turn the leaking cylinder so that gas rather than liquid escapes. Isolate the area until the gas has dispersed.

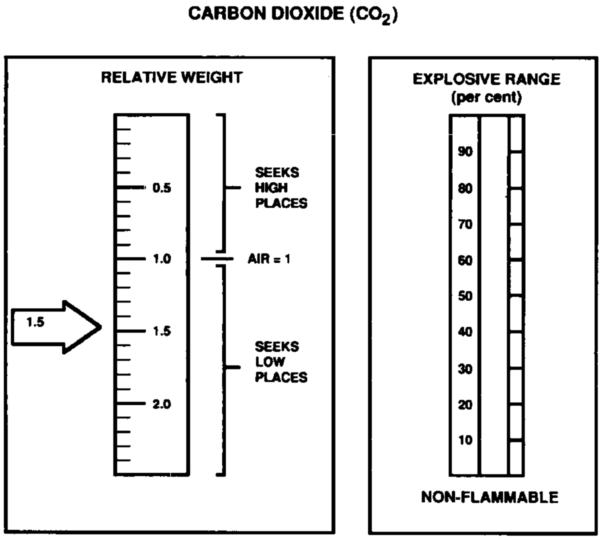
RESPIRATORY PROTECTION AND FIREFIGHTING PROCEDURES

Chemical cartridge respirators or self-contained breathing apparatus (*see* Chapter 7) will provide adequate protection against ammonia in concentrations up to 300 ppm. A supplied-air or air-purifying respirator should be worn in ammonia concentrations between 300 and 500 ppm. Concentrations of 500 ppm or more are dangerous to life. In an emergency, or planned entry into an area where there is any possibility that ammonia concentrations may exceed this level, a positive-pressure full-facepiece self-contained breathing apparatus must be worn.

Carbon dioxide, Halon and powder extinguishers are suitable for fighting fires in which ammonia is involved. Stop the flow of gas or liquid and move ammonia cylinders from the fire area if it is safe to do so. Use a water spray to keep containers cool but do not direct water at the source of an ammonia leak or a venting safety device. Pressurized containers may explode in a fire, releasing irritating ammonia gas; be prepared by wearing self-contained breathing apparatus. Ammonia is not readily ignited, but explosions of air-ammonia mixtures have occurred, particularly in confined spaces.

CARBON DIOXIDE (CO_2)

Carbon dioxide, an inert gas, is a normal constituent of mine air (Figure 3-3). It is a product of the decomposition or combustion of organic compounds in the presence of oxygen and also of the respiration of men and animals. It is a colourless, odourless gas which, when breathed in large quantities, may cause a distinctly acid taste. It will not burn or support combustion. Carbon dioxide is heavier than air and is often found in low places and abandoned mine workings. The proportion of carbon dioxide in mine air is



PROPERTIES

COLOUR: None.
ODOUR: None.
TASTE: Acid if breathed in large quantities
OTHER:

HOW FORMED

Oxidation of organic materials, rotting timber, burning wood, blasting, diesel engines, humans breathing, and as a product of complete combustion of organic materials.

THRESHOLD LIMIT VALUE AND EFFECT ON HUMANS

TLV/TWA = 5000 ppm - stimulates breathing; 50 000 ppm - increases respiration 300%; 100 000 ppm - can be endured for only short period.

TREATMENT OF AFFECTED PERSONS

Remove to fresh air. Give oxygen and artificial respiration if breathing has stopped.

Figure 3-3. Carbon dioxide – key characteristics.

increased by the process of breathing, by the burning of flame lamps, by fires, explosions and blasting, or by escape from thermal water. Clinical investigations indicate that carbon dioxide influences the respiratory rate. This rate increases rapidly with increasing amounts of carbon dioxide (*see* Table 3-2).

TABLE 3-2
PHYSIOLOGICAL EFFECTS OF CARBON DIOXIDE

CO_2 in Atmosphere (%)	Increase in Respiration
0.05	Slight.
2.00	50%.
3.00	100%.
5.00	300% and laborious.
10.00	Cannot be endured for more than a few minutes.

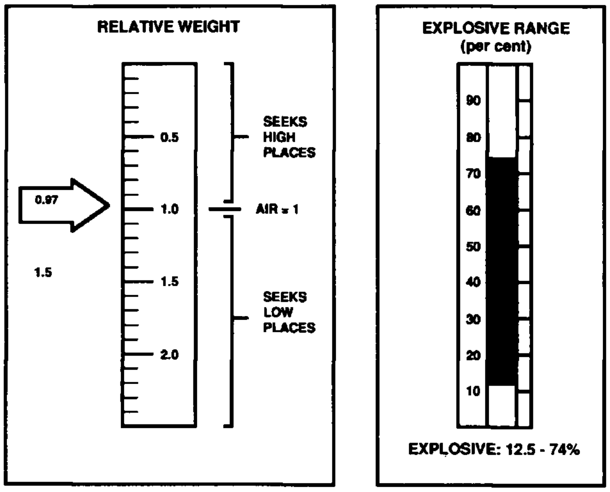
Carbon dioxide in air has these effects when the oxygen content remains approximately normal and the individual is at rest. Moving around or working increases the symptoms and the danger is greater than when resting. Concentrations of over 5 per cent carbon dioxide in the air are usually accompanied by an appreciable lowering of the oxygen content. Carbon dioxide in mine air should be not more than 0.5 per cent.

CARBON MONOXIDE (CO)

Carbon monoxide gas, or "white damp", is one of the greatest hazards to life in underground mining. It is one of the products of combustion in normal blasting operations and the operation of diesel motors and is dangerous unless adequate ventilation is provided (Figure 3-4). It is also produced by such abnormal occurrences as mine fires or gas explosions. It is a product of incomplete combustion and is formed wherever organic compounds are burned in an atmosphere with insufficient oxygen to carry the process of burning or oxidation to completion. It is a colourless, odourless, tasteless gas which, when breathed in even low concentrations, will produce symptoms of poisoning. Carbon monoxide will burn and air that contains 12.5 to 74 per cent carbon monoxide will explode if ignited. It is only slightly soluble in water and is not removed from the air to any extent by water sprays. It is slightly lighter than air, having a relative weight of 0.967.

Carbon monoxide in excess of 0.01 per cent, if breathed indefinitely, may eventually produce symptoms of poisoning; 0.02 per cent will produce slight symptoms after several hours exposure. At a concentration of 0.04 per cent, and exposure for 2 to 3 hours, headache and discomfort usually occur. With moderate exercise, a concentration of 0.12 per cent is sufficient to cause slight palpitation of the heart within 30 minutes, a tendency to stagger in 1.5 hours, and confusion of the mind, headache and nausea in 2 hours. In concentrations of 0.20 to 0.25 per cent unconsciousness usually occurs in about 30 minutes. The effect of high concentrations may be so sudden that one has little or no warning before collapsing (*see* Table 3-3; Figure 3-5). The carbon monoxide content of the air in which men are employed for a period of 8 hours should not exceed 0.005 per cent or 50 ppm.

CARBON MONOXIDE (CO)



PROPERTIES
COLOUR: None.
ODOUR: None.
TASTE: None
OTHER:

HOW FORMED
Incomplete combustion of organic materials, diesel exhaust, blasting, fires.

THRESHOLD LIMIT VALUE AND EFFECT ON HUMANS
TLV = 50 ppm - saturates blood so oxygen cannot be used. Early symptoms include tightness of skin on forehead, dizziness, nausea, confusion of mind, a pink colour to the skin and unconsciousness. Absorption by blood is cumulative.

TREATMENT OF AFFECTED PERSONS
Remove from further exposure. Give oxygen. Medical aid for acute poisoning. Keep patient at rest.

Figure 3-4. Carbon monoxide – key characteristics.

TABLE 3-3
PHYSIOLOGICAL EFFECTS OF CARBON MONOXIDE

Concentration of CO (%)	Allowable Length of Exposure
0.005	Allowable for exposure of several hours.
0.04–0.05	Can be inhaled for 1 hour without appreciable effect.
0.06–0.07	Just noticeable effects after 1-hour exposure.
0.10–0.12	Unpleasant, but probably not dangerous after 1-hour exposure.
0.15–0.20	Dangerous for exposure of 1 hour.
0.4 or more	Death in less than 1 hour.

HOW CARBON MONOXIDE ACTS

The oxygen absorbed from the air in the lungs is normally taken up by the blood in the form of a loose chemical combination with the red colouring matter (haemoglobin) of the corpuscles and is carried to the tissues where it is used. Haemoglobin forms a much more stable compound with carbon monoxide than with oxygen; when saturated with carbon monoxide it can no longer take up oxygen.

The affinity of haemoglobin for carbon monoxide is about three hundred times its affinity for oxygen, hence when even a small amount of carbon monoxide is present in the air breathed, the haemoglobin will absorb the carbon monoxide

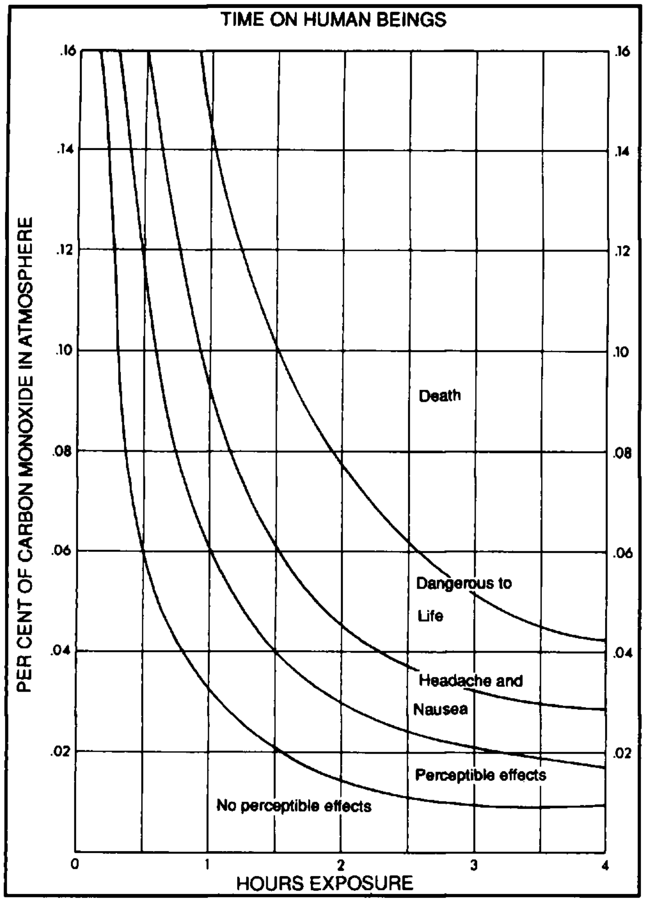


Figure 3-5. Physiological effects of exposure to carbon monoxide.

in preference to the oxygen. When carbon monoxide is absorbed it reduces the capacity of the haemoglobin for carrying oxygen to the tissues. It is this interference with the oxygen supply to the body that produces the symptoms of poisoning.

The symptoms of poisoning more or less parallel the extent of blood saturation. The first definite indications, during rest, appear when 20 or 30 per cent of the haemoglobin is combined with carbon monoxide. Unconsciousness takes place at about 50 per cent saturation and death occurs at about 80 per cent. The symptoms produced by various percentages of carbon monoxide in the blood, as determined by experiments conducted by the United States Bureau of Mines, are summarized in Table 3-4.

The symptoms decrease in number with the increase in the rate of saturation. Victims may experience few symptoms when exposed to high concentrations. The rate at which they are overcome, and the sequence in which the symptoms appear, depend on several factors: the concentration of gas, the extent to which the victims are exerting themselves, the state of their health and individual susceptibility, and the temperature, humidity and air movement to which they are exposed.

TABLE 3-4
SYMPTOMS OF CARBON MONOXIDE POISONING

Blood Saturation (%)	Symptoms
0–10	None.
10–20	Tightness across the forehead, possible headache.
20–30	Headache, throbbing in the temples.
30–40	Severe headache, weakness, dizziness, dimness of vision, nausea, vomiting and collapse.
40–50	Same as 30–40, with more possibility of fainting and collapse, increased pulse and respiration rate.
50–60	Fainting, increased pulse and respiration rate, coma with intermittent convulsions.
60–70	Coma with intermittent convulsions, depressed heart action and respiration, possible death.
70–80	Weak pulse and slowed respiration, respiratory failure and death.

Exercise, high temperature and humidity, with little or no air movement, tend to increase respiration and heart rate and consequently result in more rapid absorption of carbon monoxide.

Treatment for Carbon Monoxide Poisoning

The onset of carbon monoxide poisoning may be either sudden or gradual, depending on the concentration and period of exposure. Interest usually centres on the treatment of the acute or sudden form.

In the treatment of the chronic or gradual form of poisoning the most important factors are avoiding further exposure and taking a complete rest. In the treatment of acute carbon monoxide poisoning the most important thing is to get the gas out of the blood as quickly as possible, thus decreasing the possibility of serious after-effects or even loss of life through failure of the heart and lungs. As soon as the patient begins to breathe air in which there is no carbon monoxide, the process of eliminating the gas from the blood will begin naturally. However, this normal elimination is slow and often has serious effects. It requires from 8 to 15 hours to reduce the carbon monoxide haemoglobin to 10 per cent of the total haemoglobin. Inhalation of pure oxygen will remove the carbon monoxide from the blood four or five times faster. The use of oxygen alone, in an oxygen therapy unit, is common practice because it is usually readily available owing to its general use in industry. Inhalation treatments are preferably given with an inhalator, but the oxygen may be administered by improvised apparatus or sprayed directly over the patient's face from a cylinder if an inhalator is not at hand. Caution should be taken in controlling the flow when using the gas directly from the cylinder. The cylinder should be opened, and the flow regulated, before the gas is directed toward the patient. No improvised mask or device should be used in which pressure may build up and cause injury. Because of its great efficiency, an inhalator is preferable to any improvised device.

The steps in the effective treatment of carbon monoxide poisoning are as follows:

(1) The patient should be removed to fresh air as soon as possible.

(2) If breathing has stopped, is weak and intermittent, or is present only in occasional gasps, artificial respiration should be given persistently until normal breathing is resumed or until it is definitely established that the patient is dead.

(3) Pure oxygen should be administered, beginning as soon as possible and continuing as long as necessary, at least 20 minutes in mild cases and as long as 1 or 2 hours in severe cases.

(4) Circulation should be aided by rubbing the patient's limbs toward the heart and keeping the body warm with blankets or hot-water bottles.

(5) The patient should be kept at rest, lying down to avoid strain on the heart; later he should be given plenty of time to rest and recuperate. It cannot be emphasized too strongly that immediate inhalation of oxygen for 20 to 30 minutes will lessen the severity of carbon monoxide poisoning to a great extent and decrease the possibility of serious after-effects.

CHLORINE (Cl)

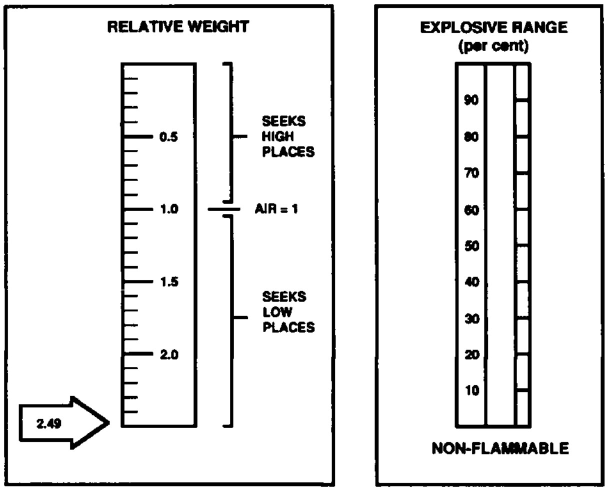
Chlorine is a heavy, greenish yellow, nonflammable gas which is easily liquefied and is supplied commercially as a liquid under pressure in cylinders and larger containers (Figure 3-6). The handling of these containers is no different from that of other compressed gas cylinders. No attempt should be made to handle or store chlorine without a complete review of the *Dow Chlorine Handbook* or the *Chlorine Manual*, available from the Chlorine Institute.

Because of its fairly low solubility in water, chlorine is an irritant to the deeper as well as the upper respiratory system. A gas mask of the acid-gas type will provide protection from concentrations up to about 2 per cent by volume in air, at which point skin irritation becomes serious. Chlorine may react to cause fire or explosion upon contact with turpentine, ether, ammonia, hydrocarbons, hydrogen, steel pipes and vessels, or finely divided metals.

A person who has been exposed to chlorine must be taken from the contaminated area and kept as quiet as possible. Rest is essential. The patient must be kept warm and quiet, lying on the back with the head elevated. A doctor should be called immediately. Serious effects may be delayed and persons who have been exposed to chlorine should consequently be kept under observation for at least 24 hours. Ingestion of chlorine gas is not a serious problem. If swallowed do not induce vomiting; give milk, water or milk of magnesia, and call a doctor immediately. Prevent inhalation and all contact with skin and eyes. If exposure occurs, effects of inhalation should be looked for first and treated, even though skin and eye contact may also have occurred. In mild cases of throat irritation from chlorine, milk will give relief. Epinephrine or ephedrine will provide relief shortly after exposure, when the distress is mainly due to bronchial spasm.

Inhalation of oxygen, or a carbon dioxide and oxygen mixture, is helpful in chlorine poisoning, particularly if positive-pressure oxygen breathing can be given. If breathing has apparently stopped, artificial respiration should be started at once. It will be more effective if oxygen inhalation can be given at the same time.

CHLORINE (Cl)



PROPERTIES

COLOUR: Greenish yellow.
ODOUR: Distinct odour; compare clorine bleach.
TASTE:
OTHER:

HOW FORMED

Electrolysis of common salt and other chemical reactions involving chlorine compounds.

THRESHOLD LIMIT VALUE AND EFFECT ON HUMANS

TVA = 10 ppm for 2 hours or 0.5 ppm for 12 hours. Corrosive irritant to eyes, skin, lungs etc.

TREATMENT OF AFFECTED PERSONS

Remove from contaminated area. Keep warm and quiet, lie on back with head elevated. Call a doctor immediately.

Figure 3-6. Chlorine – key characteristics.

In spite of the most careful inspection, compressed-gas cylinders and larger containers will occasionally leak, commonly because of unnecessarily rough handling. The Chlorine Institute gives the following recommendations for handling leaking chlorine containers:

(1) Correct the condition promptly. Telephone your chlorine supplier or any chlorine producer if you need help.

(2) Keep on the windward side and above the leak.

(3) Permit only authorized, trained personnel, equipped with gas masks, to investigate. Keep all other persons away from the affected area.

(4) If the leak is extensive, try to warn everyone in the path of the gas.

(5) If a leak occurs in equipment in which chlorine is being used, close the valve of the chlorine container immediately.

(6) If chlorine is escaping as a liquid, turn the container so that chlorine gas escapes. The amount of gas escaping from a leak is about one-fifteenth the amount of liquid which will escape through a hole of the same size.

(7) Do not apply water to a chlorine leak.

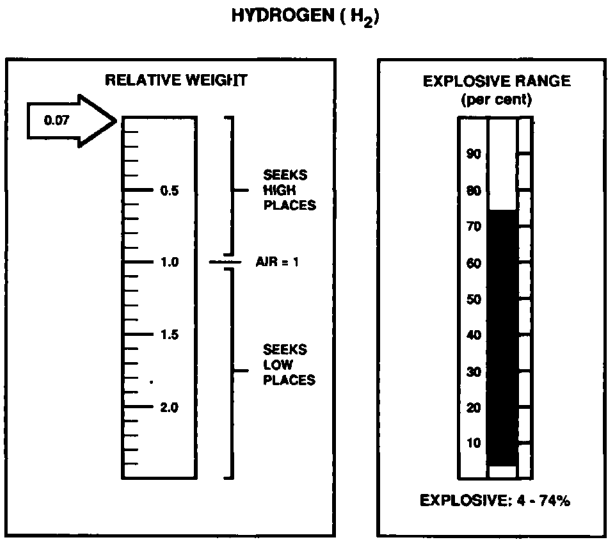
(8) If a chlorine leak occurs in transit through a congested area, keep the conveyance moving, if possible, until it reaches an open area. If the vehicle is wrecked, transfer the container to a suitable conveyance and transport it to the open country.

(9) Pinhole leaks in cylinders and large containers may sometimes be temporarily stopped by tapered hardwood pegs or metal drift pins driven into the holes. First turn the container so that only gas is escaping. Use extreme care in driving the plug because the wall area surrounding the hole may be thin and crumble. After taking this emergency measure, empty the cylinder as quickly as possible.

Mechanical devices for plugging leaks in chlorine containers of various sizes, up to tank cars, are available from suppliers of chlorine and can be kept on hand. They are highly effective if properly used.

HYDROGEN (H_2)

Hydrogen is a colourless, odourless and tasteless gas. It is very much lighter than air with a relative weight of 0.07 and is highly flammable. Hydrogen is explosive over a broad range of concentrations, that is, from 4 to 74 per cent. It will explode with as little as 5 per cent oxygen in the air and is most violently explosive at concentrations of 7 to 8 per cent (Figure 3-7).



PROPERTIES

COLOUR: None.
ODOUR: None.
TASTE: None.
OTHER: Highly explosive over a wide range of concentrations

HOW FORMED

Electrolysis in battery charging stations. Incomplete combustion and incomplete breakdown of water when rock heated to incandescence. Present in coal gas and released by blasting in coal.

THRESHOLD LIMIT VALUE AND EFFECT ON HUMANS

Nontoxic; only physiological effect is when oxygen is displaced.

TREATMENT OF AFFECTED PERSONS

As for oxygen deficiency.

Figure 3-7. Hydrogen – key characteristics.

Hydrogen is not a toxic gas and, as with methane, the only danger of breathing it is when the concentration is such that the oxygen content of the air is significantly reduced.

The only real hazard of hydrogen is from its flammable and explosive properties. Hydrogen is normally found in mine air in only very small quantities. It can, however, be produced at the time of mine fires when rock is heated to incandescence or as a result of incomplete combustion.

The most common source of hydrogen, under normal circumstances in metal mines, is in battery locomotive charging stations. The electrolytic action which takes place during battery charging releases hydrogen. Charging stations must, therefore, be well ventilated and smoking, electric arcs or any other open flame must be avoided in them.

In coal mines occurrences of small quantities of hydrogen gas are more general. From a trace to as much as 9 per cent can be found in the crevices of a coal face after blasting. It is formed there as a result of incomplete combustion of explosives and by distillation of the coal, caused by the explosion.

Hydrogen is usually present in amounts up to 2 per cent in gas from gob and ordinary mine fires and is always present after coal-dust explosions. Coal gas may contain as much as 50 per cent hydrogen.

Hydrogen gas can be detected with the multigas detector described on page 00 and with vacuum bottles.

HYDROGEN CYANIDE (HCN)

Hydrogen cyanide, also referred to as **prussic acid, hydrocyanic acid** and **formonitrile**, is a colourless, tasteless gas with a distinctive odour of bitter almonds; it condenses to a colourless liquid at temperatures below −26°C. It is a fast-acting and deadly poison causing paralysis of the respiratory system and chemical asphyxiation and is particularly dangerous as it can be absorbed through the skin as well as by inhalation (Figure 3-8).

Hydrogen cyanide is formed by the action of hydrochloric acid on cyanide compounds. It is unlikely to be found in underground mine workings, but may occur in concentrator areas where cyanide is used as a reagent in the milling of gold ore, and other places where cyanide compounds are used. It may also be released from cyanide-bearing concentrator tailings.

The threshold limit value for hydrogen cyanide is 10 ppm. The effects of exposure are shown in Table 3-5; the effects are slower for exposure to cyanide salts. The average lethal dose of sodium cyanide is 100 milligrams, whether ingested or absorbed through the skin or lungs; 200 milligrams is about the size of an aspirin tablet. In each case hydrogen cyanide enters the bloodstream and blocks the ability of red blood cells to take up oxygen. The effect is the same as suffocation.

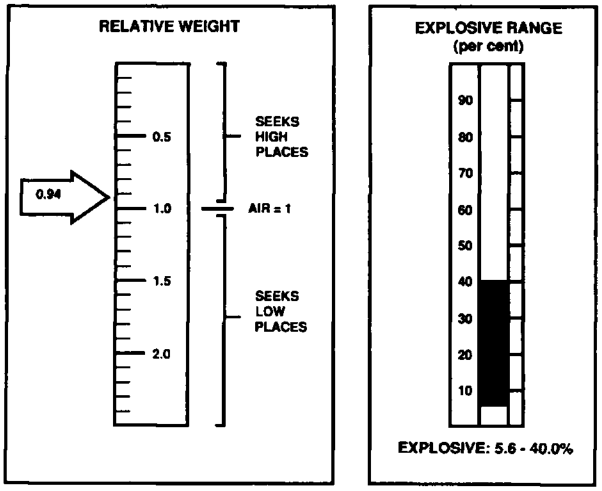
Symptoms of mild or early cyanide poisoning are:

- General weakness, heaviness of the arms and legs.
- Difficulty breathing.
- Headache, giddiness, nausea and vomiting.
- Irritation of the nose, mouth and throat.

Symptoms of severe cyanide poisoning are:

- Nausea and vomiting.
- Gasping for breath.

HYDROGEN CYANIDE (HCN)



PROPERTIES

COLOUR: None.
ODOUR: Bitter almond.
TASTE: None.
OTHER: Can be absorbed through the skin.

HOW FORMED

Action of hydrochloric acid on sodium or potassium cyanide. May occur in mill areas where cyanide is used. It may also be produced during the heat treatment of drill steel or released from cyanide-bearing concentrator tailings.

THRESHOLD LIMIT VALUE AND EFFECT ON HUMANS

10 ppm for 8 hours or 5 ppm for 12 hours. Deadly poison, causing paralysis of the respiratory system and chemical asphyxia.

TREATMENT OF AFFECTED PERSONS

Remove to fresh air. Give cyanide antedote as directed. Call a doctor immediately. A special cyanide-type cannister is required for administration of the anecdote. Use the cannister with caution.

Figure 3-8. Hydrogen cyanide – key characteristics.

TABLE 3-5
PHYSIOLOGICAL EFFECTS OF HYDROGEN CYANIDE

Concentration of HCN (ppm)	Symptoms of Exposure
18–36	Slight symptoms of poisoning after several hours.
45–54	Tolerated for 30–60 minutes without immediate or later effects.
110–135	Fatal after 30–60 minutes.
135	Fatal after 30 minutes.
180	Fatal after 10 minutes.
270	Fatal immediately.

Similar symptoms may result from other medical conditions; for example, a person who is unconscious or has breathing difficulties may have suffered a stroke or a heart attack. In any event, it is important to take immediate action. Look for firm evidence of cyanide poisoning; for example, a cyanide splash or spill, the odour of bitter almonds or several people experiencing the same symptoms. If cyanide poisoning is suspected victims should be given cyanide antidote as soon as possible but **a firm diagnosis is important as the antidote may worsen the patient's condition if cyanide poisoning is not the problem**. A doctor should be called immediately and ambulance drivers and staff at the emergency treatment centre must be told that cyanide poisoning is suspected.

SPILL PROCEDURES

In the event of a cyanide spill restrict access to the area until clean-up is completed. Ensure clean-up is done by trained personnel wearing adequate protective clothing. Ventilate the area, extinguish or remove all possible sources of ignition and remove or isolate all flammable or combustible materials. Notify government occupational and environmental authorities. Do not touch the spilled cyanide and prevent it from entering sewers or confined spaces. Stop or reduce the leak if it is safe to do so; contain the spill with earth, sand or absorbent material which does not react with cyanide.

In the case of **small spills** use nonreactive absorbent material to soak up the spilled cyanide and put it in suitable covered, labelled containers for safe disposal. In the event of a **larger spill** contact fire and emergency services, and the cyanide supplier, for advice. If the source of the spill is a leaking cylinder that cannot be shut off, remove the cylinder to a safe place in the open air then repair the leak or allow the cylinder to empty.

Review federal, provincial and local government requirements prior to disposal of spilled cyanide. Disposal by controlled incineration or secure landfill may be acceptable. Waste solutions can be decontaminated by making the solution strongly basic (pH 12) by adding caustic soda and pouring the solution onto ferrous sulphate; the resulting ferrocyanide is relatively harmless. Waste solutions can also be converted to less toxic cyanate by treatment with chlorine, sodium or calcium hypochlorite, or ozone at pH 9 to 11; use a maximum of 10 per cent hypochlorite. Decontamination must be done by trained personnel.

FIREFIGHTING PROCEDURES

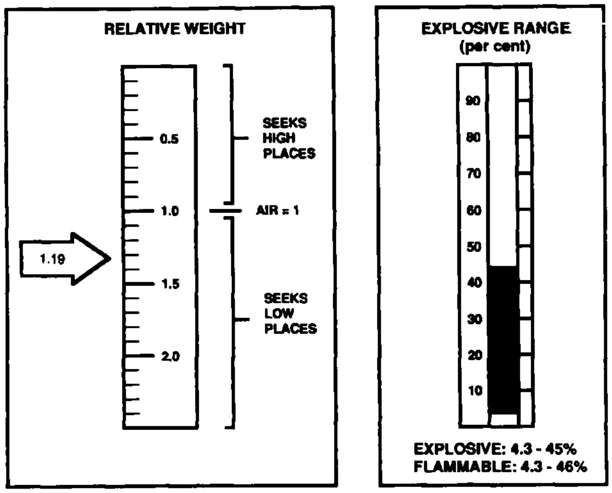
Because cyanide vapour is extremely toxic, fight fires from a safe distance or a protected location; stay upwind, avoid contact and wear a full chemical-protective suit if exposure is possible. Cyanide vapours are extremely flammable and may flow to a source of ignition and flash back. The vapours may explode if ignited in an enclosed area and containers may explode in the heat of a fire. If possible to do so safely, move cyanide containers away from the fire area and stay away from the ends of tanks. Withdraw immediately at the first sign of increasing sound from a venting device or any discoloration of the tank. In the case of a small fire, if it is not possible to stop the leak, allow the fire to burn itself out if there is no danger to the surroundings. Water may be ineffective as an extinguisher but can be used to cool containers exposed to the fire. Disperse vapours, flush spills away from occupied areas or dilute them to nonflammable concentrations and protect firefighters trying to stop the leak.

HYDROGEN SULPHIDE (H_2S)

Hydrogen sulphide, known as "stink damp", is one of the most poisonous gases known. Fortunately only traces of it are ordinarily found in mine workings. In some respects it is more dangerous than hydrogen cyanide. In low concentrations its distinctive rotten-egg smell is noticeable, but in high concentrations the sense of smell is quickly paralyzed by the action of the gas on the respiratory system and cannot be relied upon as a warning. The gas has a relative weight of

1.19 and, being heavier than air, may collect at low points (Figure 3-9).

HYDROGEN SULPHIDE (H_2S)



PROPERTIES

COLOUR: None.
ODOUR: Rotten-egg smell in low concentrations.
TASTE: None. Irritates nose, throat and eyes.
OTHER:

HOW FORMED

Burning sulphide ores, explosions of dusts from sulphide ores and action of hydrochloric acid on sulphide concentrates.

THRESHOLD LIMIT VALUE AND EFFECT ON HUMANS

TVA = 10 ppm for 8 hours or 5 ppm for 12 hours - paralyses respiratory centre. Low concentrations cause oedema of the lungs, bronchitis and pneumonia.

TREATMENT OF AFFECTED PERSONS

Remove to fresh air. Give oxygen. Give artificial respiration if breathing stopped. Get medical aid and advise of exposure to hydrogen sulphide.

Figure 3-9. Hydrogen sulphide – key characteristics.

Hydrogen sulphide inhaled in a sufficiently high concentration produces immediate asphyxiation; in low concentrations it produces inflammation of the eyes and respiratory tract and sometimes leads to bronchitis, pneumonia and oedema of the lungs.

Subacute poisoning may be produced by long exposure to concentrations as low as 0.005 per cent. Immediate collapse usually results from exposure to concentrations of 0.06 to 0.1 per cent and death quickly follows. The 8-hour daily exposure should not exceed 0.001 per cent or 10 ppm (*see* Table 3-6).

TABLE 3-6
PHYSIOLOGICAL EFFECTS OF HYDROGEN SULPHIDE

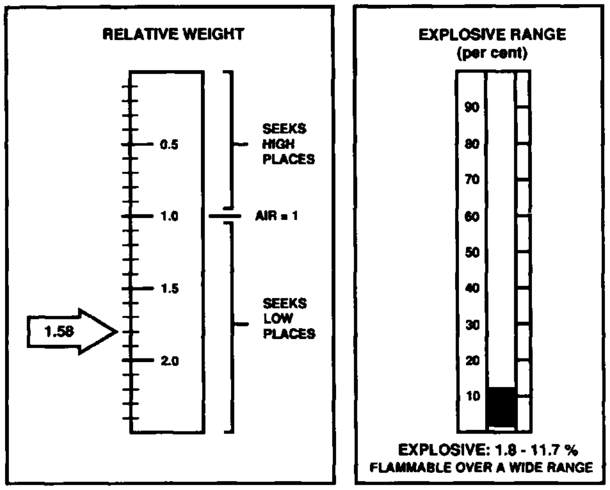
Per Cent	Effects	Time
0.001	Maximum allowable for 8-hour day	
0.005–0.010	Subacute poisoning (1) Mild eye irritation (2) Mild respiratory irritation	1 hour
0.02–0.03	Subacute poisoning (1) Marked eye irritation (2) Marked respiratory irritation	1 hour
0.05–0.07	Subacute to acute poisoning (1) Unconsciousness	½–1 hour
0.10–0.20 or more	Acute poisoning (1) Unconsciousness (2) Death	Minutes

When explosions of dust occur in blasting operations in sulphide orebodies, the resulting gases may contain varying amounts of hydrogen sulphide, together with sulphur dioxide and possibly other sulphur gases.

MAPP

A relative newcomer to the welding industry, MAPP is a methylacetylene-propadiene-propylene-propane mixture. It resembles acetylene in its combustion characteristics but differs from it in several important ways (Figure 3-10). It can replace acetylene for most brazing, cutting and heating operations.

MAPP



PROPERTIES

COLOUR: None
ODOUR: Olefinic odour.
TASTE:
OTHER: Liquefied gas under pressure. Slightly soluble in water.

HOW FORMED

Not formed accidentally. May escape from faulty cylinders.

THRESHOLD LIMIT VALUE AND EFFECT ON HUMANS

TWA = 1000 ppm. A slight irritant to the skin and nose. Due to its rapid evaporation rate it can cause frostbite on contact. Inhalation in moderate cases results in symptoms of oxygen deficiency. Very high concentrations may have an anaesthetic effect.

TREATMENT OF AFFECTED PERSONS

Treat as for oxygen deficiency. Flood frostbitten areas with lukewarm, not hot, water. The patient should see a doctor promptly if cyrogenic "burning" has resulted in blistering of the skin or deep freezing.

Figure 3-10. Methylacetylene-propadiene (MAPP) – key characteristics.

MAPP has all the best features of acetylene, natural gas and propane, and is extremely safe to use. It is a very stable gas. If, for example, a full MAPP cylinder is dropped, it will probably not explode as an acetylene cylinder might. The explosive limits are not as critical as with acetylene and consequently the risk of an explosion when using MAPP is much less and it can be used safely at higher pressures than acetylene. MAPP is noncorrosive but may form explosive acetylides if in contact with copper, silver or mercury.

Vapour from MAPP has the same dangerous asphyxiating effect as other liquefied fuels, but its characteristic strong odour provides a warning of its presence even at very low concentrations. Conscious persons who have inhaled MAPP vapour should be moved to an uncontaminated area and breathe fresh air; unconscious patients should be moved to fresh air, given mouth-to-mouth resuscitation and supplemental oxygen. MAPP is a slight irritant to the skin and, due to its high evaporation rate, it may cause tissue freezing or frostbite on skin contact with the liquid. Frozen tissue should be flooded or soaked in lukewarm, not hot, water and the patient should see a doctor promptly if the cyrogenic "burn" has resulted in blistering or deep tissue freezing.

METHANE (CH_4)

Methane or marsh gas is encountered in some metal mines in the Bridge River area and in almost all coal mines in British Columbia. Mixtures of methane with air and other gases are known as "fire damp" and "after damp". The gas is trapped in the pores of the coal and its rate of release is variable. It is formed by the decomposition of organic matter in the presence of water and the absence of air or oxygen. It is often seen as bubbles in stagnant pools, hence the name marsh gas.

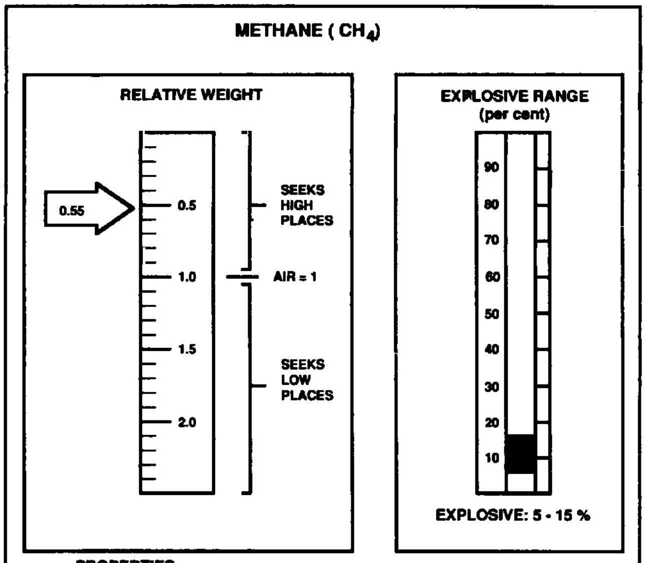
Methane is a colourless, odourless and tasteless gas. An odour caused by the presence of other gases such as hydrogen sulphide often accompanies it. Methane will burn with a pale blue nonluminous flame. Still air that contains 5 to 15 per cent methane and 12 per cent or more oxygen will explode. However, the flammable and explosive range of methane is variable and all occurrences of the gas should be considered dangerous (Figure 3-11). Where the occurrence of methane is known or suspected, adequate ventilation to dilute the gas to a harmless concentration is important.

Methane is considerably lighter than air and when found in mines is usually near the roof or in high places. Accumulations of the gas may be encountered in unused and poorly ventilated mine workings or when old workings are being dewatered. It may be produced by the decay of old timbers.

Methane has no direct effect upon humans but it may displace the oxygen in the air to such an exent as to cause oxygen deficiency. An open-flame lamp or spark may cause an explosion. The *Mines Act, Coal Mines Regulations,* requires that all workers be withdrawn from any work-heading when the methane content of the general body of air reaches 2.5 per cent. The Act also requires that electrical circuits be isolated in any work area when the methane content in the general body of air reaches 1.25 per cent and that no blasting or shotfiring is done when it exceeds 1 per cent.

NITROGEN (N_2)

Nitrogen Is a colourless, odourless and inert gas. It is not combustible nor will it support combustion. It has no physiological effect on humans and is only dangerous if it occurs in such concentrations that it dilutes the air sufficiently to cause the oxygen content to fall below the safe limit (Figure 3-12). This dilution may result from the oxidation of various substances or by consumption in an active fire, thus robbing the mine atmosphere of a part of its oxygen. The oxygen



PROPERTIES

COLOUR: None.
ODOUR: None, but often associated with other sulphurous
TASTE: gases.
OTHER: None.

HOW FORMED

Decomposition of organic matter. Released from coal seams and some other rocks during mining or diamond drilling.

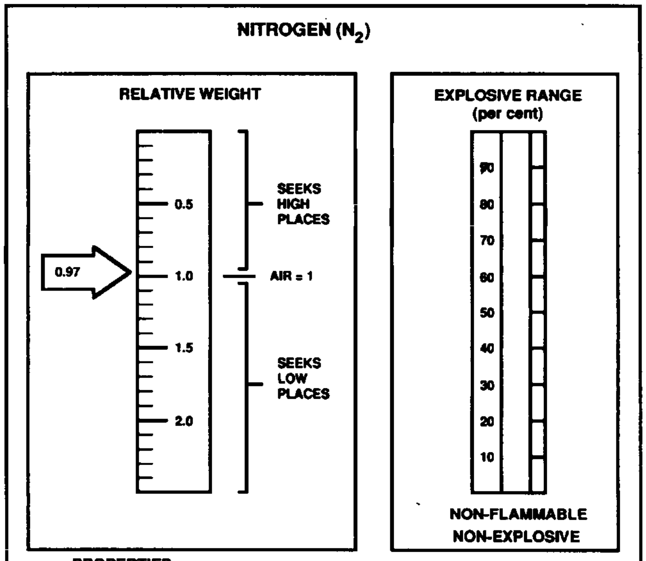
THRESHOLD LIMIT VALUE AND EFFECT ON HUMANS

Nontoxic, but due to flammability, workers must be evacuated if concentration reaches 2.5%. Blasting must be stopped at a concentration of 1%.

TREATMENT OF AFFECTED PERSONS

If concentration causes oxygen defficiency, treat as such.

Figure 3-11. Methane – key characteristics.



PROPERTIES

COLOUR: None.
ODOUR: None.
TASTE: None.
OTHER: Acts as a dilutant of oxygen in air.

HOW FORMED

Normal constituent of air, also given off by rock strata in some mines.

THRESHOLD LIMIT VALUE AND EFFECT ON HUMANS

Maximum 81% for 8 hours or 41% for 12 hours. Oxygen deficiency is experienced at high concentrations.

TREATMENT OF AFFECTED PERSONS

Remove to fresh air. Give artificial respiration if breathing has stopped.

Figure 3-12. Nitrogen – key characteristics.

content may be reduced to a very low level and the residual nitrogen mixed with the products of combustion such as carbon dioxide, carbon monoxide and sulphur dioxide.

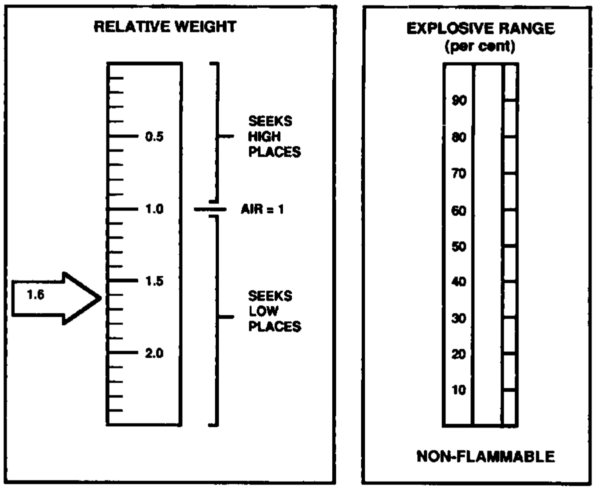
Nitrogen is a natural constituent of the atmosphere. The TLV is 81 per cent.

OXIDES OF NITROGEN (NO, NO_2, etc.)

Oxides of nitrogen are formed in mines by the burning of explosives and, to a slight extent, by their detonation. They can usually be detected by the burned-powder odour familiar to blasters and by the reddish colour of nitrogen dioxide (NO_2) fumes which are formed when the nitric oxide (NO) produced by an explosion comes in contact with the air. Gases collected from the burning of 40 per cent gelatin dynamite contain 11.9 per cent oxides of nitrogen. When explosives having properly proportioned components are completely detonated they usually produce exceedingly small amounts of oxides of nitrogen, which are considered harmless. Explosives from which the wrapper has been removed may produce harmful amounts of oxides of nitrogen even when detonated. Diesel engines also produce oxides of nitrogen. Key characteristics are summarized in Figure 3-13.

Oxides of nitrogen corrode the respiratory passages and the breathing of relatively small quantities may cause death. The effect is unlike that of carbon monoxide in that a person may apparently recover and then die suddenly several days later. Nitrogen dioxide (NO_2) is probably the most irritating of the oxides of nitrogen. Its effects on the respiratory passages are not usually noticed until several hours after exposure when oedema and swelling take place. This irritation may be followed by bronchitis or pneumonia, frequently with fatal results. Air containing 0.01 per cent nitrogen dioxide may cause dangerous illness if breathed for a short time and a concentration of 0.07 per cent is fatal if breathed for about 30 minutes and sometimes less (Table 3-7). The maximum acceptable concentration and TLV/TWA for this gas are both 3 ppm. In other words, the concentration for any short period of exposure must not be greater than that for an 8-hour exposure.

OXIDES OF NITROGEN (NO and NO_2)



PROPERTIES

COLOUR: None in small concentrations; reddish brown in higher concentrations.
ODOUR: None.
TASTE: Acid if breathed in large quantities.
OTHER:

HOW FORMED

Diesel exhuast, blasting with dynamite or ammonium nitrate blasting agents.

THRESHOLD LIMIT VALUE AND EFFECT ON HUMANS

TLV/TWA = 3 ppm. Corrosive to tissues of lungs and respiratory tract; causes oedema of the lungs.

TREATMENT OF AFFECTED PERSONS

Remove to fresh air. Give oxygen and complete rest. Obtain medical aid.

Figure 3-13. Oxides of nitrogen – key characteristics.

TABLE 3-7
PHYSIOLOGICAL EFFECTS OF OXIDES OF NITROGEN

Concentration of Oxides of Nitrogen		
Parts per Million	Per Cent	Effect
3	0.0003	Maximum allowable for 8-hour day.
60	0.006	Minimum causing immediate throat irritation.
100	0.01	Minimum causing coughing.
100–150	0.01–0.015	Dangerous for even short exposure.
200–700	0.02–0.07	Quickly fatal after short exposure.

OXYGEN (O_2)

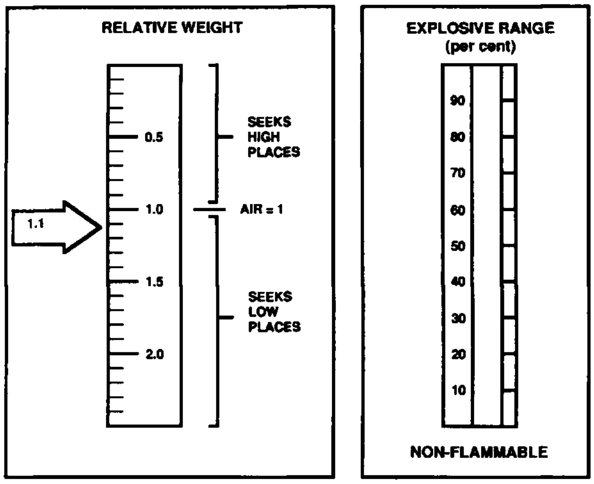
Oxygen, a colourless, odourless and tasteless gas, is the most important constituent of air. It is necessary for the support of life and combustion. Its key characteristics are summarized in Figure 3-14. People breathe most easily and work best when the air contains approximately 21 per cent oxygen, but they can live and work, though not as well, when there is less. When the oxygen content is about 17 per cent, men at work will breathe a little faster and more deeply. The effect is about the same as moving from sea level to an altitude of 1500 metres (5000 feet). People breathing air containing as little as 15 per cent oxygen usually become dizzy, notice a buzzing in the ears, have a rapid heartbeat and often suffer headaches. Very few people are free from these symptoms when the oxygen level in the air falls to 10 per cent. Mine air should contain not less than 18 per cent oxygen (*see* Table 3-8).

TABLE 3-8
PHYSIOLOGICAL EFFECTS OF OXYGEN DEFICIENCY

Oxygen Present (%)	Effect
21	Breathing easiest.
17	Breathing faster and deeper.
15	Dizziness, buzzing noise, rapid pulse, headache, blurred vision.
9	May faint or become unconscious.
6	Movement convulsive, breathing stops, shortly afterwards heart stops.

The flame of a safety lamp or candle is extinguished when the oxygen level falls to about 16 per cent. A carbide-lamp flame will burn in an atmosphere containing as little as 12.5 per cent of oxygen.

OXYGEN (O_2)



PROPERTIES

COLOUR: None.
ODOUR: None.
TASTE: None.
OTHER: Oxygen deficiency is detected by a candle or safety lamp. The flame will go out when the oxygen level falls to approximately 16%

HOW DEPLETED

Oxygen deficiency is caused by humans breathing in confined space, absorption of oxygen by water, consumption of oxygen by fire, etc.

THRESHOLD LIMIT VALUE AND EFFECT ON HUMANS

Mine air should contain at least 18% oxygen. High concentrations are not harmful, but oxygen is essential to life. Symptoms of oxygen deficiency are buzzing in the ears, rapid breathing, confusion of the mind, and ultimately death.

TREATMENT OF PERSONS AFFECTED BY OXYGEN DEFICIENCY

Remove to fresh air. Give oxygen and artificial respiration if breathing has stopped.

Figure 3-14. Oxygen – key characteristics.

As oxygen is more soluble in water than nitrogen, air exposed to water in a confined area will probably have a lowered oxygen content. As an example, the oxygen content of the air from a hydraulic compressed air plant is lowered to about 17.7 per cent with a consequent rise in the nitrogen content.

Oxygen levels higher than the normal 20 to 21 per cent apparently have no injurious effects. This is found to be the case in the use of self-contained oxygen breathing apparatus. There is no noticeable effect after successive periods of use. High oxygen levels, as used with the oxygen breathing apparatus, help men to work with less fatigue. However, it is dangerous to breathe pure oxygen at a pressure much higher than 100 kilopascals (15 psi) for a very long time. The irritating effects of oxygen are only found in human beings after they have been exposed to an atmosphere containing 80 per cent oxygen for 48 hours or more.

The effects of oxygen deficiency near or below sea level are the same as those due to the reduction of oxygen at high altitudes. At approximately 7 per cent oxygen the face becomes leaden in colour, the mind is confused and the senses dulled. When there is no oxygen in the atmosphere loss of consciousness occurs in a few seconds, without any warning symptoms. Loss of consciousness in air deprived of oxygen is quicker than in drowning; not only is the supply of oxygen cut off, but oxygen already in the lungs is quickly used up. Loss of consciousness is quickly followed by convulsions, then by cessation of breathing. Oxygen levels may be low enough to endanger life before the danger is realized.

Some of the causes of oxygen deficiency underground are:

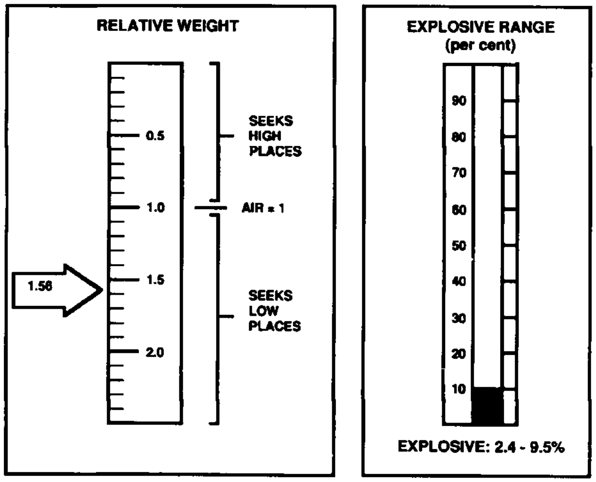
- Absorption by water or certain types of rock, ore or fill.
- The breathing of people in confined space.
- Displacement by carbon dioxide, carbon monoxide or other gases.
- Heating conditions or combustion.

PROPANE (C_3H_8)

Propane, a liquefied petroleum gas also referred to as bottled gas, has become very popular as a temporary heat source on construction sites for heating tar kettles and many other applications associated with construction work. Common sense handling, and using propane with properly designed equipment, makes it a safe, useful and economical fuel. Its key characteristics are summarized in Figure 3-15.

Propane is extracted from natural and refinery gases. It is normally a vapour at temperatures above its boiling point (−42°C; −44°F). The boiling point is the temperature at which the liquid gas will convert into vapour at atmospheric pressure. It is compressed into a liquid state and will remain a liquid under pressure when stored in special pressure-containers such as cylinders.

PROPANE GAS (C_3H_8)



PROPERTIES

COLOUR: None.
ODOUR: None, commercially scented.
TASTE: None.
OTHER: Inflammable and explosive.

HOW FORMED

Commercially produced petroleum distillate.

THRESHOLD LIMIT VALUE AND EFFECT ON HUMANS

TVA/TWA = 1000 ppm for 8 hours or 500 ppm for 12 hours. Displaces oxygen.

TREATMENT OF AFFECTED PERSONS

Ventilation. Remove to fresh air. Give oxygen and artificial respiration if breathing has stopped.

Figure 3-15. Propane – key characteristics.

USE AND STORAGE OF PROPANE CYLINDERS

Always use, store and transport cylinders in an upright position. In this position the relief valve section of the cylinder valve is in contact with vapour space in the cylinder, as it is intended to be. Propane containers are never charged completely full of liquid. A vapour space must be maintained above the liquid level to allow for liquid expansion caused by increased temperature. Standard cylinders are charged with 45 kilograms (100 pounds) of liquid gas.

Do not use, store or transport cylinders in a horizontal position. Cylinders lying horizontally allow liquid gas to reach the relief valve. If it were required to function, due to abnormal pressure, liquid gas would escape from the valve. It would also allow liquid to flow to vapour-consuming appliances. Both conditions are unsafe.

Vapour-withdrawal containers are normally used with temporary heaters and for other applications around construction sites. Liquid-withdrawal propane cylinders are also available. They are used for specialized applications, as with tar kettles or compound heaters using special self-vaporizing liquid burners. These cylinders are to be used outdoors only. They are identified by a tag on the cylinder valve marked LIQUID and are painted a distinctive colour. DO NOT ATTEMPT TO INTERCHANGE LIQUID-WITHDRAWAL CYLINDERS WITH VAPOUR TYPE.

Liquid-withdrawal cylinders are to be used in the upright position; they have a dip tube extending to the bottom of the cylinder so liquid propane is withdrawn through the valve. However, the relief valve is in communication with the vapour space in the cylinder, as with the vapour-withdrawal type.

Propane is odourless but additives give it a foul and uncommon smell so that leaking gas can be detected before a flammable mixture has accumulated. Should you detect a smell of gas, close the valve at the container and, if unable to remedy the source of leak, call your propane serviceman.

Propane vapour is heavier than air. Any escaping gas will seek out low places, such as excavations, to collect and create flammable mixtures. Never use matches or fire to check for leaks; use soap solution that will create bubbles at the point of leak.

The heat required to convert liquid propane into vapour within the container is obtained from surrounding air when the temperature is above −42°C (−44°F). This heat transfer is limited to the area wetted by the liquid in the container at time of use. Withdrawal from the container at a rate greater than this heat-transfer capacity will cause refrigeration of the liquid gas. It will reduce both the temperature and pressure within the container and cause heavy frost accumulations on the outside, at about its liquid level line. This signifies the load on the container is becoming too great for efficient operation.

When using propane, make sure cylinders are placed on a solid footing or secured to prevent tipping and falling over. The thawing of ice or frozen ground should be anticipated. Full and empty cylinders not in use should be stored on a solid footing, at ground level in a specified area outdoors, where they will be protected against abnormal increases in temperature, tipping over, physical damage, or tampering. Cylinder valves must be closed and valve-protecting collars or caps in place.

When in use, place cylinders and pressure-regulating equipment where they will not be damaged, at least 3 metres (10 feet) away from heating appliances. Shield cylinders from radiated or blower heat at all times. Protect hoses or piping from damaging traffic and excessive heat. Cylinder valves must be protected from physical damage with valve-protecting collars while in use, and with collars or caps while in transit or storage. Use only hoses and regulating equipment approved for liquefied petroleum gas propane services. Hoses and fittings rated for 125-pound (60-kilogram) working pressures are not to be used for liquid gas services, however, hose and fittings rated for liquefied petroleum gas [350-pound (160-kilogram) working pressure] may also be used on vapour services.

When converting to vapour, liquid propane will expand to about 270 times its liquid volume. This explains why so much heating value can be stored in small containers. It also explains why escaping liquid gas is more dangerous than vapour escaping from a leak of the same size.

It is recommended that only one propane cylinder be attached to each temporary heater when installed inside buildings under construction. Under special conditions, where additional cylinders are required, no more than three cylinders [total 300 pounds (135 kilograms) of gas] shall be manifolded together. Where more than one manifold is required for multiple heater installations, separate the manifolds by at least 15 metres (50 feet). Cylinders must be at least 3.5 metres (12 feet) from heaters. Regulators must be connected directly to cylinder valves or otherwise adequately supported.

Excess-flow check valves are supplied as a safety feature with propane equipment, either as an integral part of the cylinder valve, the pressure regulator inlet connector, or manifold fittings for attachment to the cylinders. The function of these check valves is to shut off the flow of gas from cylinders in the event they are accidently tipped over and the regulator or manifold connectors are broken off.

Always open cylinder valves very slowly to prevent premature closing of these check valves. If the cylinder valve is opened too fast, close the check valve, shut off the cylinder valve, wait a minute for the check valve to open again, and then very slowly open the cylinder valve until the line to the heater is full of gas. When this has been done, open the cylinder valve fully as a partially open valve will not permit the excess-flow check valve to function properly. Do not force the cylinder valve open beyond the normal stop (this is approximately one and one-half to two turns of the valve handle).

Always use heating appliances equipped for use with liquefied petroleum gas approved safety shut-off valves, so that in the event pilot lights are extinguished, the gas supply to the appliances will be automatically shut off. Do not use appliances utilizing bimetal strips for a safety shut-off as they are not approved for liquefied petroleum gas services.

Do not operate gas appliances in confined or unventilated areas. Propane needs air for combustion. Most buildings under construction will have adequate ventilation, but where space is confined, provide ventilation (near the floor and ceiling level) to carry off the products of combustion and to provide air for good combustion.

Do not drop cylinders. Be sure the valve-protecting cap is in place and the cylinder valve closed when moving them. Check gas connections for leaks with soap solutions, never with matches or flame.

Check with your insurance underwriter and with the local authorities (safety inspection) having jurisdiction for approvals or any additional requirements.

SULPHUR DIOXIDE (SO_2)

Sulphur dioxide is another gas produced by burning sulphide ores, by blasting in sulphide ores or explosions of sulphide ore dust. Some diesel fuels also produce sulphur dioxide when used in a diesel engine.

The gas has a strong sulphurous smell which is suffocating and very irritating to breathe (Figure 3-16). It is so irritating that it cannot be tolerated for any length of time in dangerous concentrations. It is colourless and has a distinctly acid taste. A person's natural reaction to the smell of the gas is to get out of it and this, of course, is the best thing to do.

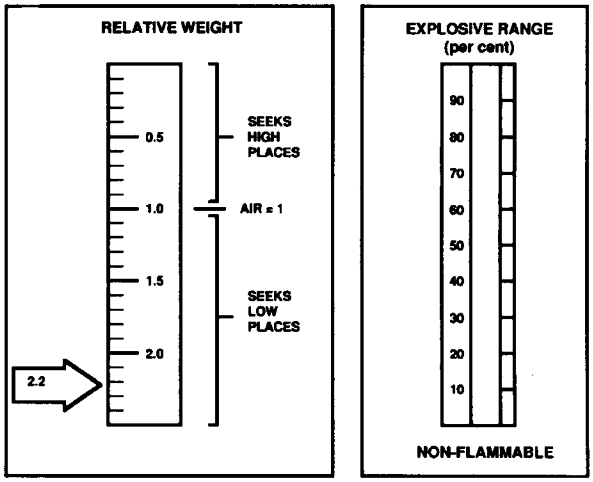
If forced to breathe this gas for any length of time, coughing and nausea result. The gas will affect the lungs in much the same way as oxides of nitrogen and hydrogen sulphide. Irritation of the respiratory tract and lungs will cause oedema (Table 3-9).

TABLE 3-9
PHYSIOLOGICAL EFFECTS OF SULPHUR DIOXIDE

Concentration of Sulphur Dioxide		
Parts per Million	Per Cent	Effect
2	0.0002	Maximum allowable for an 8-hour day.
20	0.002	Coughing, irritation of eyes, nose and throat.
150	0.015	May be endured for several minutes.
400	0.04	Impossible to breathe.

Sulphur dioxide is highly soluble in water, in fact it is one of the most soluble gases found in mines. Like chlorine, it is a very heavy gas and will accumulate in low places.

SULPHUR DIOXIDE (SO_2)



PROPERTIES
COLOUR: None.
ODOUR: Strong, pungent sulphurous smell.
TASTE: Acid taste.
OTHER: Very irritating to breathe

HOW FORMED
Burning sulphide ores, blasting in sulphide ores, sulphide dust explosions, and some diesel fuels.

THRESHOLD LIMIT VALUE AND EFFECT ON HUMANS
TLV/TWA = 2 ppm. Causes irritation of eyes, throat and lungs; intolerable to breathe in dangerous concentrations.

TREATMENT OF AFFECTED PERSONS
Remove to fresh air. Give oxygen and artificial respiration if breathing has stopped. Obtain medical aid.

Figure 3-16. Sulphur dioxide – key characteristics.

TABLE 3-10
CHART OF MINE GASES

Name	Symbol	Relative weight (air = 1)	Solubility grams per 100 cc water at 41°F	Properties	How formed	When dangerous	Threshold limit value	How detected	Flammable	Explosive	Effect	Treatment
Acetylene	C_2H_2	R.W. = 0.91	0.05	Gas Inflammable Colourless Distinct odour	Water on calcium carbide.	Explosive range 2.8%–81%. Tank may explode on shock, i.e., by dropping; pressure sensitive above 15 psi.		Odour	Yes	Yes	Displaces oxygen.	As for O_2 deficiency.
Air	Air	R.W. = 1.0	0.00295	Colourless Odourless Tasteless	Constituents O_2 20.94% N_2 78.09% CO_2 0.03% Traces of other gases.	If O_2 falls below 16% or when poisonous gases enter.	Minimum 19.5% to 18%. O_2 for 8 hours.	For O_2 with safety lamp and gas detection.	No	No	If O_2 below and man working 17% panting, 15% dizziness, 9% collapse, 7% fatal.	Ventilation. Fresh air. If unconscious, give artificial respiration.
Ammonia	NH_3	R.W. = 0.6	Highly soluble in water	Colourless Strong odour Caustic action	Combination of hydrogen and nitrogen with catalytic action.	When exposed to oxidizing substances and heat, becomes explosive.	25 ppm	Odour detector.	Yes	Yes	Corrosive irritant to eyes, nose, throat and lungs.	Fresh air, rest.
Carbon dioxide	CO_2	Much heavier than air R.W. = 1.53	1.237	Colourless Odourless Tasteless in low concentrations. Acid taste in high concentrations. Induces rapid breathing.	Normal constituent of mine air. From breathing of humans and animals, from decay of animal and vegetable matter. Released from thermal water and from some rock strata. Mine fires.	Above 2% causes greatly increased lung ventilation up to collapse.	Maximum 0.5% for 8-hour exposure.	Analysis of vacuum bottle sample. Detectors. Displaces O_2 and will therefore extinguish lamp at high concentration.	No	No	At 2% increases lung ventilation by 50%. At 3% increases ventilation by 100%. At 5% increases ventilation by 300%. May displace oxygen.	Provide fresh air and oxygen. If unconscious, give artificial respiration.
Carbon monoxide	CO	Lighter than air R.W. = 0.97	0.003559	Colourless Odourless Tasteless Poisonous	From incomplete combustion. Blasting, diesel exhaust, underground fires.	Depends on concentration and length of exposure. 0.4% death in less than 1 hour. 0.15–0.20% for 1 hour. 0.04% for 1½ hour. Headache and nausea.	0.005% or 50 ppm; 8-hour exposure maximum.	CO detector, canary, vacuum bottle sample, assay.	Yes, in certain concentrations.	12.5–75.0%	Headache, nausea, death. Dangerous after-effects. Pink to red skin colour.	Fresh air, O_2 if nauseated or unconscious. Artificial respiration if not breathing. Rest.
Chlorine	Cl_2	Much heavier than air R.W. = 2.49	1.06	Greenish yellow gas	Various ways chemically but principally from electrolysis of common salt.	Above 1 ppm.	1 ppm	Odour	No	No	Corrosive irritant to eyes, skin, lungs, etc. Use Type "N" mask up to 2% concentration.	As for oxides of nitrogen.

TABLE 3-10 — *Continued*
CHART OF MINE GASES

Name	**Symbol**	**Relative weight (air≐1)**	**Solubility grams per 100 cc water at 41°F**	**Properties**	**How formed**	**When dangerous**	**Threshold limit value**	**How detected**	**Flammable**	**Explosive**	**Effect**	**Treatment**
Hydrogen	H_2	Lighter than air R.W. = 0.0695	0.0001756	Colourless Odourless Tasteless	Thermal water. Battery charging. Electrolysis of water. Product of incomplete combustion in explosions and mine fires. Corrosive action of strong acids on metal (iron).	No harmful effects.		Laboratory analysis of gas sample. Would give indication on detectors using Wheatstone bridge resistance measurement.	Yes	Yes, 4.1–74% with as little as 5% O_2. Violently explosive 7–8%.	None, except may displace O_2.	Treat for low O_2.
Hydrogen cyanide; Prussic acid	HCN	Slightly lighter than air R.W. = 0.0941	Slightly soluble	Smell of bitter almonds. Deadly poison.	Hydrochloric acid on sodium or potassium cyanide. May occur in mill areas where cyanide is used. Produced during heat treating of drill steel. May be released from tailings where cyanide has been used for mineral recovery.	10 ppm	10 ppm	Smell of bitter almonds. Detector.	Gas–yes	Gas–yes	Paralyzes respiratory system developing chemical asphyxia. Absorbed through skin as well as in lungs.	Fresh air. Give cyanide antidote as directed. Get doctor. Type "N" canister not satisfactory. Special cyanide type canister required. Use mask with extreme caution.
Hydrogen sulphide	H_2S	A little heavier than air R.W. = 1.19	0.5276	Colourless. Smell of rotten eggs. Irritates eyes and respiratory tract. Poisonous.	Decomposition of some sulphur compounds. Blasting in sulphide ores. Hydrochloric acid spilled on sulphide concentrate or ore. Thermal waters. Underwater decomposition of vegetable matter.	+0.01% acute poisoning. 0.07% rapid unconsciousness. +0.05% dangerous. +½ hour 0.002–0.003%*.	0.001% or 10 ppm for 8 hours.	Rotten-egg odour. Detectors. Eye irritation.	Yes, 4.3–45% if enough O_2.	Yes, 4.3–45% will explode.	Sense of smell deadened. After 1 or 2 inhalations will paralyze the respiratory system.	Fresh air. Artificial respiration if unconscious. Get to doctor.
MAPP	Mixture	R.W. = 1.58	Slightly soluble	Liquefied gas Inflammable Colourless Distinct odour	Commercially manufactured.	Explosive range 1.8–11.7%.	1000 ppm	Odour	Yes	Yes	Displaces oxygen.	As for O_2 deficiency.
Methane	CH_4	Much lighter than air R.W. = 0.55	0.00717	Colourless Odourless Tasteless	Decay of certain bacteria or organic matter in coal measures and in some metal mines in contact with carbonaceous rock. Decaying timber.	When displaces O_2 or explosive when 5–15% present with at least 12% O_2.	Withdrawal point for men 2.5%. Electric motors stopped at 1.25%. Blasting stopped at 1%.	Flame safety lamp when in excess of 1.25%. Methane detector.	Yes	Yes, *see* column 8. Maximum explosive force at 9.0%.	No effect physiologically except can displace O_2.	As for O_2 deficiency.

TABLE 3-10 – *Continued*
CHART OF MINE GASES

Name	Symbol	Relative weight (air = 1)	Solubility grams per 100 cc water at 41°F	Properties	How formed	When dangerous	Threshold limit value	How detected	Flammable	Explosive	Effect	Treatment
Nitrogen	N_2	A trifle lighter than air R.W. = 0.97	0.002365	Colourless Odourless Tasteless Acts as a dilutant of O_2 in air.	Normal constituent of mine air. Highly concentrated N_2 has been reported to issue from rock strata in some mines.	High N_2 concentration, displaces O_2 in air.	Maximum 81% for 8-hour exposure.	Analysis of vacuum bottle sample. Displaces O_2 and will therefore extinguish lamp at high concentrations.	No	No	No effect but O_2 shortage exprienced in high concentrations.	Provide fresh air. If unconscious, give artificial respiration.
Oxides of Nitrogen	NO NO_2 N_2O_4 N_2O_2 N_2O N_2O_3 N_2O_5	Heavier than air R.W. = 1.59	NO_2 0.007747	Colourless in low concentration. Reddish brown in high concentrations. Odourless Tasteless Poisonous	From blasting or burning of dynamite. Diesel exhaust. Burning or decomposition of nitrates or nitrated material.	0.01% may be fatal in ½ hour.	0.0003% or 3 ppm maximum exposure at any time.	Detector	No	No	Toxic, will cause oedema of lungs. Delayed effect.	Complete rest. Give O_2. See doctor and advise of exposure to oxides of nitrogen.
Oxygen	O_2	A trifle heavier than air R.W. = 1.1	0.005498	Colourless Odourless Tasteless Non-poisonous at ordinary temperatures and pressures.	Regenerated by plant life.	*See* air.	*See* air.	Safety lamp and candle go out at 16.25% O_2. Carbide light goes out at 12.5% O_2.	No	No	*See* air	*See* air.
Powder smoke	Consists of small particles of carbon, tarry substances, solid and liquid matter in air.	About the same as air.	N.A.	Smoky odour of nitrous fumes. Irritates eyes, has CO and NO_2 mixed in it. Poisonous.	Product of incomplete combustion during blasting.	When CO and NO_2 content above acceptable limit.	Regulated by *Mines Act* on use of explosives.	Odour, colour of nitrous fumes. CO and NO_2 detectors.	Yes, if flammable gases are present in sufficient quantity.	Yes, under certain conditions.	Headache, dizziness, nausea, throat irritation.	Remove to fresh air or give O_2. If unconscious, give artificial respiration.
Propane	C_3H_8	R.W. = 1.56	0.1 approx.	Gas Inflammable Tasteles Colourless Odourless Scented commercially	Petroleum distillate.	Explosive range 2.4–9.5%.	1000 ppm	Safety lamp, methanometer.	Yes	Yes	Displaces oxygen.	As for oxygen deficiency.
Sulphur dioxide	SO_2	Much heavier than air R.W. = 2.20	Highly soluble in water 16.80	Colourless Suffocating Irritating with strong sulphur smell, acid taste, poisonous.	Blasting in or burning of sulphide ores. Some diesel fuels may have appreciable sulphur present and will form SO_2 on burning.	400 ppm dangerous even for short exposure. 50 ppm subacute poisoning. Irritation to throat and lungs. 20 ppm irritating to eyes. Coughing caused.	0.0002% or 2 ppm for 8 hours exposure.	Odour of burning sulphur. Irritating to eyes and respiratory tract. Detector.	No	No	Irritating to eyes, throat and lungs. Produces oedema of lungs.	Fresh air. Artificial respiration if not breathing. Get to doctor.

CHAPTER 4

OXYGEN THERAPY

TRAINING OBJECTIVES

In the previous chapter, the instruction "Give oxygen" appears frequently in the treatment recommended for people overcome by toxic gas. Clearly it is imperative that all members of mine rescue crews be familiar with the techniques of oxygen therapy.

The objectives of this chapter are to ensure that trainees know and understand the following:

- **The benefits of oxygen therapy.**
  - How to recognize improvement in the patient's condition.
- **When to use oxygen therapy.**
  - How to recognize general hypoxia.
- **The hazards of oxygen therapy.**
  - The hazard of open flame.
  - The hazard of static electricity.
  - The hazard of oil and grease.
  - The hazard of using oxygen therapy on patients suffering from chronic obstructive pulmonary disease (COPD).
- **The assembly and use of oxygen-therapy equipment.**
  - The procedure for safe handling of oxygen cylinders, regulators and masks.
  - How to test and refill oxygen cylinders.
  - How to assemble the component parts of an oxygen-therapy unit.
  - The procedure for starting and controlling oxygen flow.
  - How to administer a measured flow of oxygen.
  - How to calculate the duration of flow from a cylinder.

Students will be required to demonstrate the ability to assemble all component parts and produce oxygen at a specified flow rate.

WHEN TO USE OXYGEN THERAPY

Oxygen is essential to life and for normal cell function. Any condition that affects the supply, transport or exchange of oxygen for carbon dioxide in the bloodstream can cause hypoxia, inadequate oxygenation of body tissues (Figure 4-1). Supplementary oxygen during treatment for injuries may significantly increase a victim's chances of survival. Direct mouth-to-mouth resuscitation is the simplest and fastest way to provide it, but only delivers 16 per cent oxygen. An oxygen-therapy unit provides more concentrated oxygen and is therefore much more effective. Industrial operations and many residential camps and parks have oxygen-therapy units available, but they should only be operated by persons knowledgable and well trained in how and when to use them.

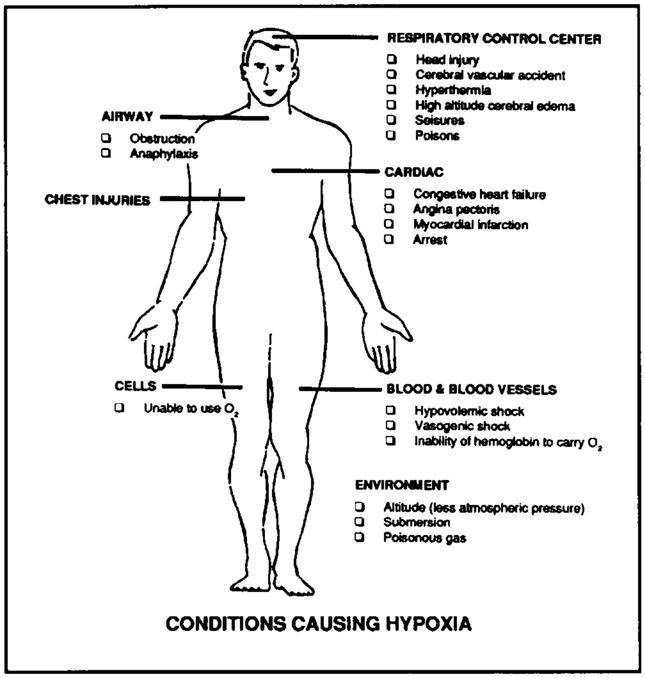


Figure 4-1. Conditions causing hypoxia.

A patient with the following symptoms may be hypoxic and will benefit from supplementary oxygen:

- Increased respiratory rate.
- Pallor.
- Agitation and irritability.
- Nausea.
- Drowsiness.
- Dyspnea.
- Cyanosis.
- Confusion.
- Vomiting.
- Headache.
- Loss of consciousness.

BENEFITS OF OXYGEN THERAPY

The benefits of oxygen therapy, which should always be explained to the patient, include:

- Increases oxygen supply to injured tissue and thus promotes healing.
- Increases the amount of oxygen carried to vital organs (the brain in particular) by the available blood supply.
- Improves the function of the heart by:
  - providing extra nourishment to the heart muscle.
  - reducing the volume of blood that must be pumped by each heartbeat.

- Reduces unnecessary movement of chest, diaphragm and abdomen (expansion of the chest is not as great). This will reduce pain in injuries to these areas.
- Enriches the oxygen content of the reduced volume of air reaching the lungs in the event of partial respiratory obstruction.
- Improves the tone of muscular walls of blood vessels.
- Improves gaseous exchange in congested lungs and within tissue spaces.

Improvement in the patient's condition will be indicated by:

- Slowing pulse rate.
- Loss of pallor, improving colour.
- Reduced pain.
- Reduced apprehension and restlessness.
- Reduced dilation of the pupils of the eyes.

CONTRA-INDICATIONS: PATIENTS WITH CHRONIC BREATHING PROBLEMS

There are many conditions where the use of oxygen therapy will be beneficial, even when the patient appears to be breathing normally. However, patients with a chronic obstructive pulmonary disease (COPD), such as emphysema or chronic bronchitis, may react adversely. In these conditions, high levels of carbon dioxide accumulate in the blood and gradually desensitize the brain to its presence. Normally, high levels of carbon dioxide in the blood signal the need to increase the respiration rate. In patients with COPD this reflex is lost, so the breathing response is triggered by low levels of oxygen; however, as the amount of oxygen in the blood must fall to almost half its normal level before this happens, COPD patients are frequently hypoxic. Administering oxygen to such a patient removes the trigger, causing a further decrease in respiration rate. Extremely high levels of carbon dioxide accumulate and can lead to confusion, unconsciousness, and eventual death by respiratory arrest.

Oxygen should still be administered to COPD patients, but at a low flow-rate of approximately 1 to 2 litres per minute. If severe hypoxia is evident, the flow-rate can be increased, but the patient must be monitored carefully for signs of respiratory depression.

THE OXYGEN-THERAPY UNIT

The oxygen-therapy unit has three essential components; an oxygen cylinder, a regulator and facemask (Figure 4-2):

Oxygen cylinders: Oxygen is supplied in the form of compressed gas contained in a steel or aluminum cylinder. The gas is compressed to between 2000 and 2200 pounds per square inch (approximately 15 000 kPa). The size and capacity of cylinders varies according to manufacturer's standards, and is designated by a letter. There are three types of medical-oxygen cylinder in common use in British Columbia: the D and E-size units and Stewart Oxygen Service (SOS) units. At times, in remote locations, commercial-welding oxygen cylinders are used because of their large capacity [size K; 6.9 cubic metres (245 cubic feet)].

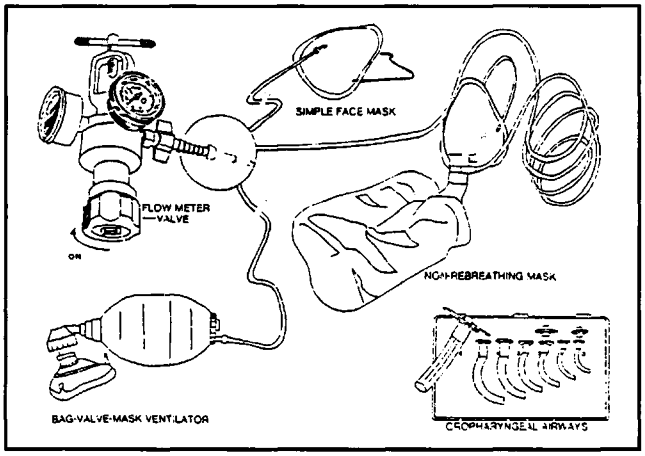


Figure 4-2. Oxygen-therapy equipment; regulator, gauges and facepieces.

Pressure regulators: A regulator reduces the pressure of gas leaving the cylinder to 40 to 70 psi (275–485 kPa) an acceptable range for administration. Two gauges are usually mounted on the regulator; one measures the pressure remaining in the tank and the other the rate of oxygen flow. The regulator is attached to the cylinder by a yoke. Each yoke is pin-indexed to fit only medical-oxygen cylinders, eliminating the risk of connecting the wrong kind of gas (Figure 4-3).

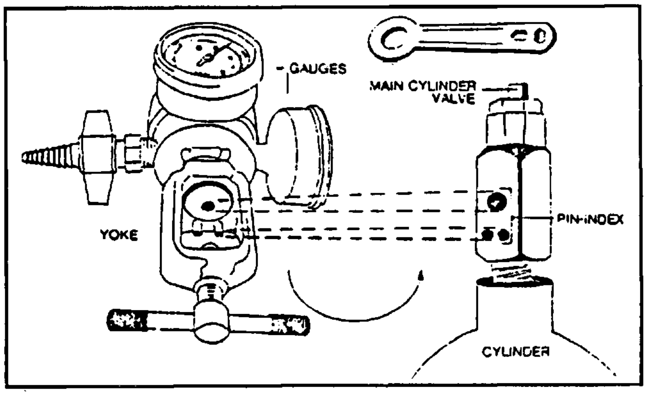


Figure 4-3. Regulator, pin-indexed yoke and medical post; D-size medical-oxygen unit.

Larger cylinders are usually threaded instead of pin-indexed, and accept screw-on regulators with the same diameter thread. A larger regulator and gauges with a female 540-thread fit directly onto the male threads on K-size commercial-welding cylinders (Figure 4-4).

It is important to remember that each type of regulator and gauges fits only one type of cylinder. Connecting mismatched cylinders and regulators requires the use of an appropriate adaptor. The adaptor used to connect the smaller sized pin-indexed regulator and gauges to the larger 540-thread commercial cylinder is illustrated in Figure 4-5. Similarly, the larger 540-thread regulator can be fitted onto pin-indexed medical cylinders using the adaptor yoke illustrated in Figure 4-6. It is not necessary to use both types of adaptors. Either type is effective and the choice is up to the company providing the first aid services.

Facemask: Several models of face mask are in common use.

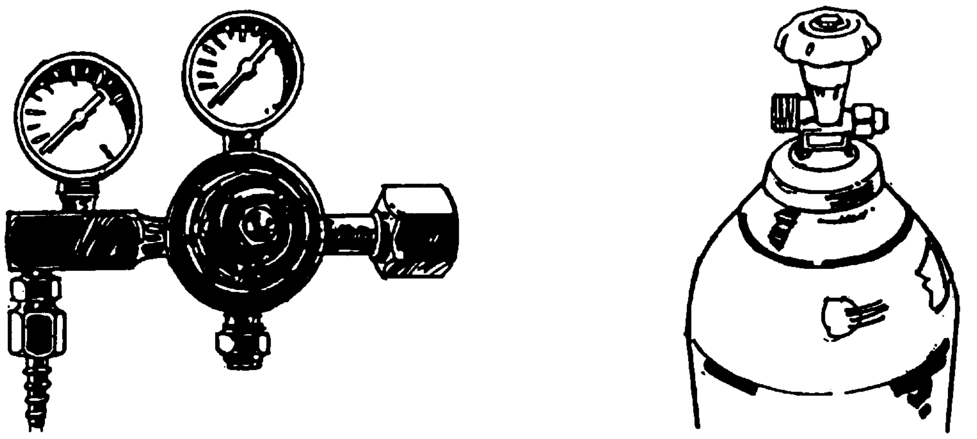


Figure 4-4. Threaded regulator and gauges for use with commercial-welding K-size oxygen cylinder.

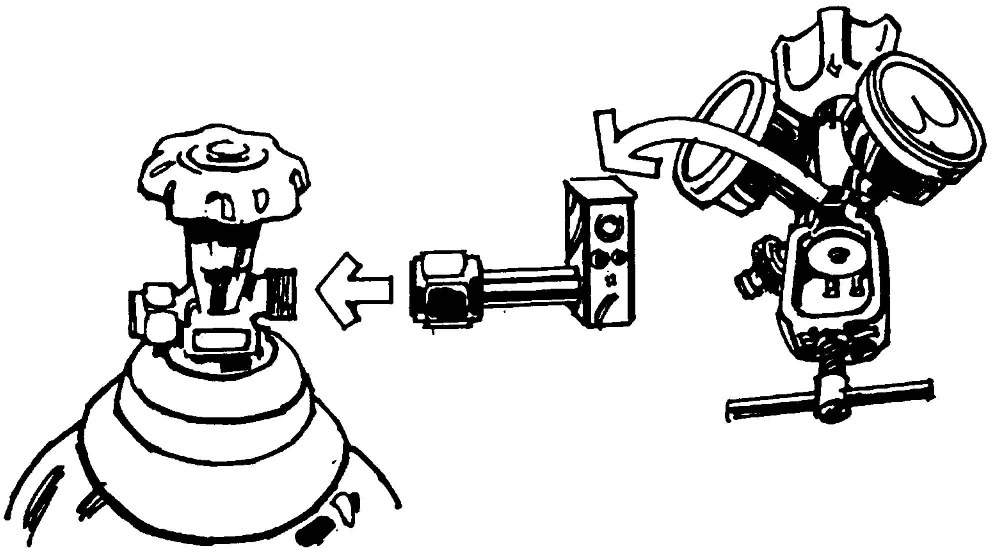


Figure 4-5. Assembly of (left to right) commercial oxygen cylinder, adaptor for connecting pin-indexed regulator to 540-thread commercial oxygen cylinder, and pin-indexed regulator.

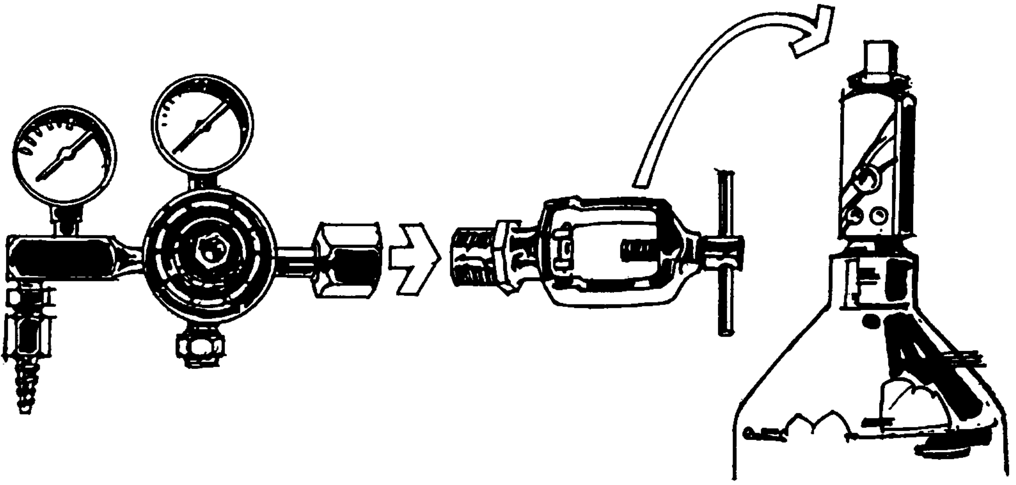


Figure 4-6. Assembly of (left to right) 540-thread regulator, adaptor yoke for connecting pin-indexed medical post to 540-thread regulator, and medical-oxygen cylinder.

OPERATING PROCEDURE

When oxygen cylinders are received from the supplier or returned after being recharged, there is usually a piece of plastic tape covering the oxygen aperture and a new gasket underneath the tape. Before attaching oxygen-delivery equipment to the cylinder, the tape must be removed and the cylinder "cracked". This means opening the valve on top of the medical post to allow some oxygen to escape. This clears any dust or foreign material that may have lodged in the aperture.

When the yoke is placed in position over the medical post and the gasket is in place, the yoke is tightened with the hand screw. BEFORE OPENING THE VALVE ON THE CYLINDER, ENSURE THAT THE REGULATOR IS TURNED OFF. Turn the valve counterclockwise at least one full turn and watch the pressure gauge. The gauge should indicate the pressure in the cylinder.

The procedure for administering oxygen therapy is summarized as follows:

- Reassure the patient and explain the benefits of oxygen therapy. Many patients have never seen oxygen equipment and it may cause some uneasiness or alarm. A mask can feel quite suffocating to a hypoxic patient.
- Check for a history of respiratory disorders.
- Attach the appropriate facepiece to the oxygen unit.
- Ensure that nobody is smoking in the vicinity.
- Slowly open the main cylinder valve until the tank pressure registers on the pressure gauge.
- Open the flow-meter valve until the desired flow-rate is reached and wait a few seconds for the line to clear of moisture and dust. It is reassuring to allow the patient to hold the mask to his face with the oxygen flowing, and when he is accustomed to it, slip the elastic band of the mask over his head to hold the mask in position.
- A patient with severe hypoxia should be started on a flow of 10 litres per minute, decreasing the flow as the patient's condition improves. A flow of 4 to 6 litres per minute should be sufficient for a mildly hypoxic patient.
- Calculate the duration of flow as the oxygen may have to be rationed. A low flow over a longer period is usually more beneficial than abruptly stopping a high flow. A rule of thumb for determining the duration of oxygen supply from a D-size medical-oxygen bottle is about 3 minutes for every 690 kPa (100 psi) at a flow-rate of 6 litres per minute; 2.5 minutes at a flow of 8 litres per minute, and 2 minutes at a rate of 10 litres per minute: i.e.

  "D" 13 800 kPa (2000 lbs.) @ 6 LPM = 3.0 × 20 = 60 minutes
  10 350 kPa (1500 lbs.) @ 10 LPM = 2.0 × 15 = 30 minutes
  6900 kPa (1000 lbs.) @ 8 LPM = 2.5 × 10 = 25 minutes

  The approximate duration of oxygen flow from K-size commercial-welding cylinders at varying pressures is shown in Table 4-1.

TABLE 4-1
APPROXIMATE DURATION OF OXYGEN FLOW FOR K-SIZE CYLINDERS
[6.9 cubic metre (245 cubic foot) capacity]

Pressure		Flow Rate		
kPa	psi	6 L/min.	8 L/min.	10 L/min.
13 800	2000	17 hr. 30 min.	13 hr.	10 hr. 30 min.
10 350	1500	13 hr.	9 hr. 50 min.	7 hr. 50 min.
6 900	1000	8 hr. 45 min.	6 hr. 30 min.	5 hr. 15 min.
3 450	500	4 hr. 20 min.	3 hr. 15 min.	2 hr. 35 min.

- Record details of oxygen therapy on the patient's monitoring chart, including start and finish time, and flow-rate. This information will be useful to medical personnel interpreting changes in the patient's vital signs.
- When therapy is complete, shut off the flow-meter valve until the gauge reads zero.
- Shut off the main cylinder valve.
- Reopen the flow-meter valve to bleed out residual air.
- Close the flow-meter valve. Gauges can be damaged if stored under continuous pressure.
- Check the amount of oxygen left in the cylinder to ensure having an adequate amount for any emergency.
- Clean the facemask with soap and water and use a good antiseptic (not alcohol) to wipe the mask after rinsing with clear water. Plastic facemasks must not be autoclaved or boiled.

CYLINDER REPLACEMENT

The procedure for replacing an empty cylinder is essentially the same as for the initial hook-up:

- Ensure the cylinder is upright. The operator should face away from the yoke.
- Slowly open or "crack" the new tank with the wrench provided with the unit. Once a jet of gas has been released, quickly close the valve.
- Check to ensure that the pressure regulator is the proper type for the cylinder and attach it securely to the tank.

STORAGE AND SAFE HANDLING OF GAS CYLINDERS

Oxygen bottles, and all other cylinders containing high-pressure gas, must be treated with care and respect. The following precautions should be observed:

- When moving cylinders, the valve-protector cap must be in place; never hoist a cylinder by the protective cap.
- If moved by crane, cylinders should be in a proper cradle or other safe container.
- Never use a sling or an electromagnet to lift cylinders.
- Avoid dropping cylinders on the ground; they could burst or valves might be broken off or seriously damaged. Dragging or sliding cylinders across the ground may also result in damage.
- When moving cylinders, use a cylinder-truck; cylinders must be upright and well secured.
- When in use, cylinders must either be on a truck or chained to a firm support so they will not topple over.
- Cylinders must never be used as rollers or supports for anything.

- Never try to transfer gas, even the same gas, from one cylinder to another. Never mix gases in a cylinder or try to fill a cylinder that has contained one gas, with another gas.
- Cylinders should be stored in specifically assigned places, away from elevators, stairs or gangways.
- Never strike an electric arc on a cylinder.
- Avoid placing cylinders where they may become part of an electric circuit and cause a fire through accidental arcing.
- Keep cylinders well away from open flames (including welding and cutting torches), electric arcs, molten metal or slag, sparks, and excessive heat of all kinds. Even exposure to the hot sun for long periods may cause a dangerous rise in gas pressure inside the cylinder.
- Always check carefully for, and eliminate, any gas leaks at cylinder valves, regulators and torch connections. This reduces the possibility of fire resulting from flying sparks and explosive atmospheres developing during periods of non-use. Use soapy water, never an open flame, to check for leaks.
- A leaking cylinder must be taken out-of-doors and clearly tagged if the leak cannot be stopped by tightening the valve packing nut. Return the cylinder to the supplier when empty; it is illegal to ship a leaking cylinder because of the obvious hazards involved.

SAFE PRACTICES IN OXYGEN THERAPY

To summarize, **safe practices in oxygen therapy require that the following rules are strictly observed:**

- Keep oil, grease, greasy clothing and similar substances away from the yoke, regulators, valves, hoses, mask or patient. Remember that oil coming in contact with oxygen under high pressure may explode.
- Remember that although oxygen does not burn or explode, it does aid combustion. No smoking should be allowed anywhere near the unit. Make sure your patient is not carrying matches or smoking materials. This NO SMOKING rule must be rigidly enforced, and signs to this effect should be posted conspicuously in all First Aid rooms.
- Crack the cylinder valve, to clear any foreign matter blocking the aperture, before connecting the regulator and gauges. Turn the opening away from you while doing so.
- Stand to one side when attaching pressure regulators or opening valves; a loose regulator can blow off with a force sufficient to inflict serious injury.
- After the regulator is in place, attach the facepiece, making sure that the flow-regulating valve is in the OFF position, then turn on the cylinder valve. Read the tank-pressure gauge. When certain that the regulator is properly mounted and this gauge is operating properly, open the flow-meter valve to obtain the desired rate of flow. Allow a few seconds for the line to clear of moisture and dust and then apply the mask or facepiece to the patient.
- Do not use electrical heating devices or infrared lamps on a patient while oxygen therapy is in progress.
- UNQUALIFIED PERSONS SHOULD NEVER, UNDER ANY CIRCUMSTANCES, ATTEMPT TO REFILL A CYLINDER. The refilling of small cylinders from larger ones is extremely hazardous and should be avoided. Return your empty cylinders to qualified recharging plants for refilling under recognized safety and control procedures.
- Whether in service, storage or transit from one to the other, keep oxygen cylinders in a box or secured in an upright position. Do not allow them to be dropped or to strike each other violently as a valve may open and the cylinder could become a dangerous projectile.
- Do not store oxygen cylinders near flammable or combustible materials such as oil, grease, gasoline, alcohol or ether; or near sources of heat such as boilers or steam pipes. Keep them in a cool, well-ventilated place.
- Keep the regulator and hose closed when not in use.
- Test oxygen cylinders at least every 10 years to ensure that they can still safely hold high pressure.

Observance of these rules may prevent serious and utterly unwarranted accidents.

CHAPTER 5

GAS-DETECTION INSTRUMENTS

TRAINING OBJECTIVES

The objectives of this chapter are to ensure that trainees understand the methods used for detecting and monitoring mine gases and airborne contaminants, and are familiar with the following detection instruments:

- Flame safety lamp.
- Gas-detector pump and Dräger tube.
- Gastec gas detector.
- Vacuum bottle and vacu-sampler.
- Electronic gas-testing devices.
- J-W gas detector.

Students will be required to demonstrate the ability to use all these instruments effectively.

INTRODUCTION

Gas detectors are used to measure the concentration of a gas. There are two basic types; the sample tube and the electronic sensor. A few of the more common types, in use at many mine properties, are described here. There are many other makes and models. Mine rescue crews must become thoroughly familiar with the instruments in use at the mine where they work. Details of the operation of each make and model will be found in the manufacturer's instructions.

Numerous consumer and industrial products, many of which are potentially dangerous, are in common use at many mine properties. Mine rescue personnel must become familiar with where the products are stored and used. Preplanning for emergency situations resulting from accidents involving any hazardous product is essential. Pertinent information on various products and materials can be obtained by reading hazardous product legislation and from the manufacturers.

FLAME SAFETY LAMP

The flame safety lamp is a device used for determining if the mine atmosphere will or will not support combustion or life, and for detecting methane gas and the presence of excess nitrogen or black damp in mine air. The Koehler flame safety lamp is illustrated in Figures 5-1 and 5-2.

The lamp has three gauzes, burns naphtha and is magnetically key locked. Magnetically locked safety lamps are the only permissible flame safety lamps to be used when flammable gases are present. The magnet to open them must not be used in the presence of a flammable gas.

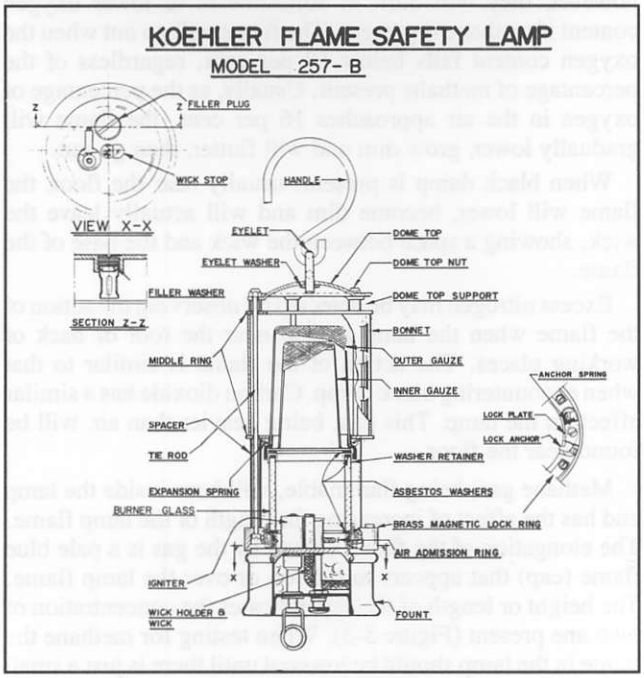


Figure 5-1. The Koehler flame safety lamp (from Koehler Manufacturing Company, Marlborough, Massachusetts).

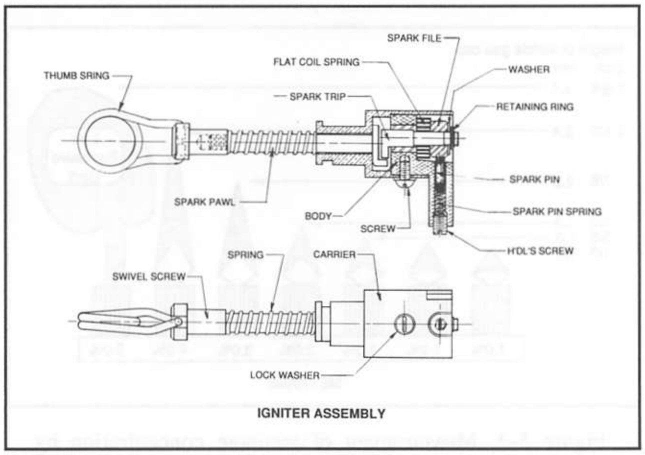


Figure 5-2. Igniter assembly of the Koehler flame safety lamp (from Koehler Manufacturing Company, Marlborough, Massachusetts).

The air feeding the lamp enters through a single gauze below the wick and the gases of combustion from the lamp exit above the wick, through double gauzes. These gauzes are made of steel-wire mesh having 11 wires to the centimetre (28 wires to the inch) or 121 openings to the square centimetre (784 openings to the square inch). The gases of combustion pass through the double gauzes and are cooled by the mesh absorbing their heat. It is this cooling effect that allows the lamp to be used where combustible gases may be encountered. Combustible gases such as methane may burn within the lamp but the resulting flame will be cooled below the ignition point of the gas surrounding the lamp as it passes through the double gauze. However, the safety lamp is only safe when it is assembled correctly and used carefully by a competent person. The flame must be kept fairly low at all times and the lamp removed when a high level of methane is encountered, so that the gauzes do not overheat. The flame from burning gases within the lamp will pass through the gauzes if they become red hot and unable to absorb any additional heat from the flame.

Flame safety lamps will not burn in a methane-free atmosphere having an oxygen content below 16.25 per cent, however, they will burn in atmospheres of lower oxygen content if methane is present. The flame will go out when the oxygen content falls below 13 per cent, regardless of the percentage of methane present. Usually, as the percentage of oxygen in the air approaches 16 per cent, the flame will gradually lower, grow dim and will flutter, then go out.

When black damp is present, usually near the floor, the flame will lower, become dim and will actually leave the wick, showing a space between the wick and the base of the flame.

Excess nitrogen may be detected by observing the action of the flame when the lamp is held near the roof or back of working places. The action of the flame is similar to that when encountering black damp. Carbon dioxide has a similar effect on the lamp. This gas, being heavier than air, will be found near the floor.

Methane gas, being flammable, will burn inside the lamp and has the effect of increasing the length of the lamp flame. The elongation of the flame caused by the gas is a pale blue flame (cap) that appears to ride on or over the lamp flame. The height or length of the cap indicates the concentration of methane present (Figure 5-3). When testing for methane the flame in the lamp should be lowered until there is just a small yellow flame visible. This method will allow the blue cap of the burning methane to be more visible.

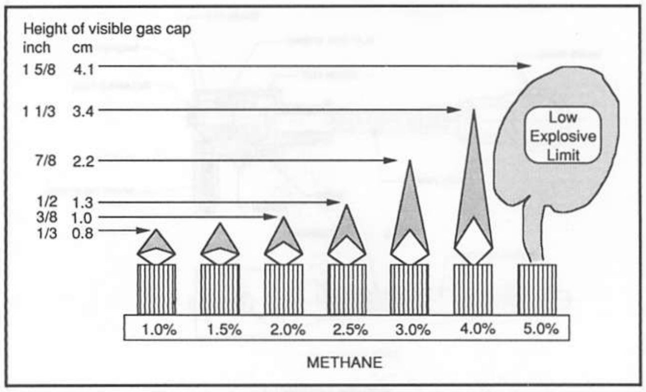
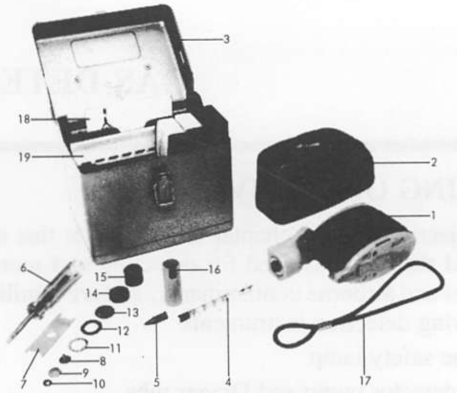


Figure 5-3. Measurement of methane concentration by height of flame in the safety lamp.

THE GAS-DETECTOR PUMP AND DRÄGER TUBE

The Dräger Multi-gas Detector consists of two parts, the gas-detector pump and the Dräger tube, chosen according to the gas expected (Plate 5-1). The unit is supplied in a metal carrying case. A protective bag for the pump and spare parts is also supplied with the unit. Accessories for the Dräger Multi-gas Detector are:

- Pump stroke counter.



1	Bellows pump model 31	11	Washer
2	Protective bag	12	Rubber ring
3	Carrying case	13	Packing disk
4	DRÄGER tube *)	14	Valve seat
5	Rubber cap	15	Rubber bung
6	Special screw-driver	16	Break-off husk
7	Special spanner	17	Carrying loop
8	Valve disk	18	Operating instructions
9	Sieves	19	Table
10	Gasket		

* The DRÄGER tubes are not included in the initial kit but have to be ordered separately according to the specified type of gas.

Plate 5-1. Dräger multi-gas detector.

- Extension tube [3 metres (10 feet) long], with bag, for sampling inaccessible places.
- Hot air probe for the investigation of furnace waste gases.
- Supplementary part for the respiratory CO test.
- Motor vehicle exhaust probe for the investigation of exhaust gases.
- Mixing device.
- Dust sampler.

The advantages of the Dräger gas detector are:

- Operation with one hand.
- Low weight and simple operation.
- Always ready for use.
- Dräger tubes for about a hundred different gases and vapours.
- Printed measuring scale on the Dräger tubes.
- Immediate reading of the result on the Dräger tube.
- Optimum accuracy of measurement.
- Maintenance-free bellows pump.

This instrument consists of a spring-loaded rubber bellows with a capacity of 100 cubic centimetres (6 cubic inches) of air and a replaceable indicator tube. Air to be tested is drawn directly into the indicator tube before passing into the bellows and the instrument requires no purging before inserting the tube. The outlet valve of the bellows has so little resistance that the air will not return through the testing tube.

The Dräger gas detector is designed to test for a number of gases by using various indicator tubes. Although indicator tubes are available from other sources, only Dräger tubes are to be used with the Dräger tester, otherwise serious errors may occur in the test readings. We are concerned here primarily with testing for carbon monoxide.

Different types of indicator tubes are available for testing for low and high quantities of carbon monoxide. The low-range tubes are used in testing carbon monoxide at concentration levels of 10 to 3000 ppm (0.001 to 0.3 per cent). The high-range tube, identified by a yellow band, is used for testing carbon monoxide at levels of 0.3 to 4 per cent. All tubes contain filtering chemicals to remove hydrocarbons and other gases that could affect the reading on the instrument.

INSPECTING THE DETECTOR BEFORE USE

The bellows should be squeezed once or twice to be sure the outlet valve is operating. To test the air-tightness of the detector, break one sealed end of the Dräger tube. Do not break the other end. Place the broken end of the tube in the inlet and collapse the bellows. The bellows will remain collapsed unless the outlet valve is leaking. It is not necessary to check the time taken for the bellows to inflate as that action is controlled by the resistance built into each indicator tube. If the outlet valve is leaking, the valve cover should be removed and the valve seat inspected or cleaned.

USE OF THE DETECTOR

To use the detector, select the proper carbon monoxide indicator tube, depending on the concentration of carbon monoxide that is expected due to conditions that are known. Break the sealed ends of the tube by inserting them in the breaker attached to one end of the drag chain on the bellows. Insert the tube firmly into the detector inlet so air will flow in the direction of the arrow on the tube. Squeeze the bellows fully to expel the residual air and then allow the bellows to refill completely. If the air sampled contains carbon monoxide, a dark stain will be seen extending downwards through the white crystals. The amount of carbon monoxide is measured by the distance the stain extends into the crystals. The reading is taken at the lowest level of general discoloration and not at the deepest point of colour penetration.

All tubes have a band on the upper end on which data concerning the test can be recorded. Tubes, once coloured, will not change colour for several hours and so can be read later under better lighting conditions than found in testing areas underground. Tubes that have been used and no colour reaction obtained may be reused up to 10 times in one day, or until colour is found. Once coloured, they must not be used again.

When testing diesel exhaust or other mixtures of hydrocarbons for carbon monoxide, a carbon pretube filled with activated charcoal should be used as an additional filter to prevent the hydrocarbons from reaching the testing crystals. Exhaust gas should not be sampled directly from the manifold, but should be passed through some form of cooler to bring the temperature into the range of 10 to 40°C (50 to 110°F).

The example described above is based on testing for carbon monoxide. As this apparatus is a multi-gas detector, a wide range of detector tubes are available for different contaminants. Each different indicator tube has its own characteristics and method of use, making it impossible to have a working knowledge of how to use them all. This is not a problem as each new box of tubes contains a data sheet providing all the information needed to make a test with the type of tube in that particular box. It is important that anyone using a multi-gas detector should know how to read the data sheet.

COMMON APPLICATIONS OF THE DRÄGER MULTI-GAS DETECTOR

- Controlling the threshold limit values of contaminated air in work areas.
- Testing tanks, sewers and manholes before entry.
- Tracing leaks in gas pipes and reservoirs.
- Detecting gas losses in certain types of processing facilities such as recovery plants.
- Identifying unknown gaseous contaminants by using different detector tubes.
- Measuring the hydrogen sulphide level in refinery gases and sewage disposal plants.
- Controlling carbon dioxide concentrations in greenhouses, fermenting rooms, grain silos and fruit storage rooms, and testing for leaks in carbon dioxide extinguisher systems.
- Measuring the carbon dioxide content in flue gas or forklift and vehicle exhaust gases.
- Adjustment of the fuel injection pump in diesel engines.
- Quickly measuring the percentage of carbon monoxide in exhaled air or in samples of blood.

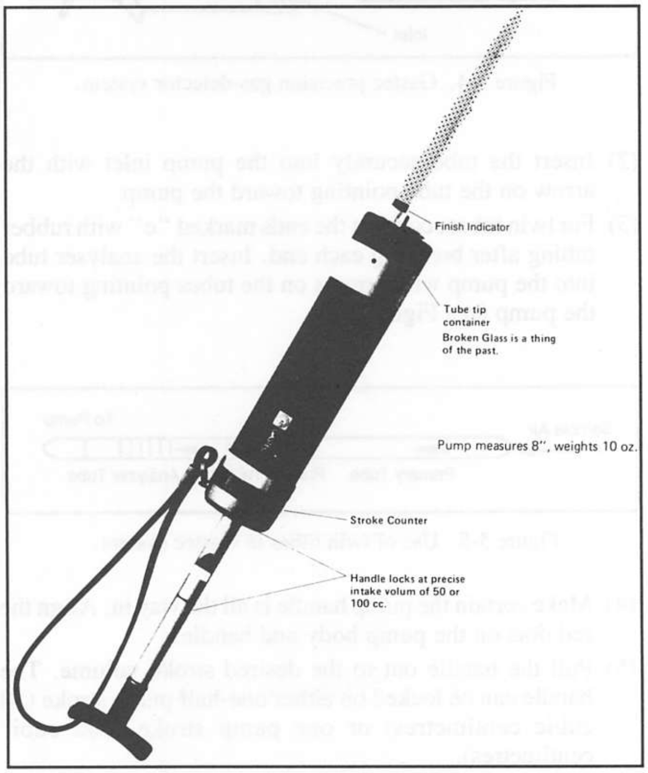


Plate 5-2. Gastec gas detector.

THE GASTEC GAS DETECTOR

The Gastec gas detector (Plate 5-2) works on similar principles to the Dräger gas detector. It consists of two components with the following features:

- **Sampling Pump**
  - the Gastec design does not require flow-rate orifices.
  - the intake volume is precisely measured (50 or 100 cubic centimetres).
  - the lubricant seal packing provides completely leak-proof sampling at all times.
- **Detector Tube**
  - direct-reading calibration scale printed on each tube.
  - the small-diameter sampling tubes provide long stain-length with one stroke of the pump.
  - sensitive reagents with high reaction rates provide a clear line of colour stain.

Each detector tube contains a precise amount of colorimetric detecting reagents and is hermetically sealed at both ends. The reagents are sensitive to specific gases or vapours; the length of stain produced by the reaction in the tube is a direct measure of concentration.

SAMPLING AND MEASUREMENT PROCEDURE

(1) Break the tips off a fresh detector tube by inserting the ends in the tube-tip breaker of the pump (Figure 5-4).

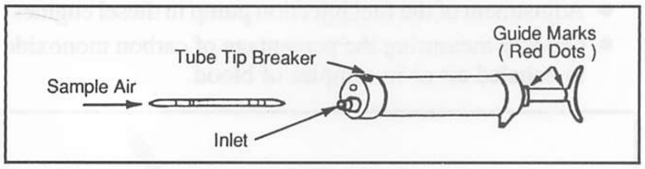


Figure 5-4. Gastec precision gas-detector system.

(2) Insert the tube securely into the pump inlet with the arrow on the tube pointing toward the pump.

(3) For twin tubes, connect the ends marked "c" with rubber tubing after breaking each end. Insert the analyser tube into the pump with arrows on the tubes pointing toward the pump (*see* Figure 5-5).

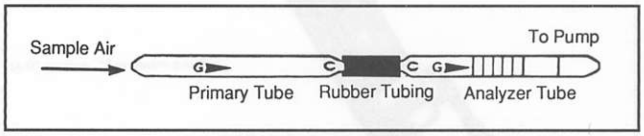


Figure 5-5. Use of twin tubes in Gastec system.

(4) Make certain the pump handle is all the way in. Align the red dots on the pump body and handle.

(5) Pull the handle out to the desired stroke volume. The handle can be locked on either one-half pump stroke (50 cubic centimetres) or one pump stroke (100 cubic centimetres).

(6) Read the concentration at the interface of the stained and unstained reagent when staining stops. Unlock the handle by making a one-quarter turn and return it to the starting position.

(7) If no reading is obtained, additional pump strokes may be made using the same tube.

THE VACUUM BOTTLE AND VACU-SAMPLER

If both the type and and concentration of gases in an area are unknown the atmosphere should be sampled using either a vacuum bottle or a vacu-sampler. Both are simple to use. To sample with a vacuum bottle, first break off the tip allowing the ambient air to fill the vacuum in the bottle, then secure the sample by placing a rubber plug in the broken tip. When taking a sample with the vacu-sampler, first ensure that the closure tape is unbroken, then hold the activator button down for at least 10 seconds.

The following information must be recorded on the container as soon as the sample has been taken:

- Sample identification.
- Date and time.
- Location.
- Temperature (°C).

The samples are then analysed by gas chromatography.

ELECTRONIC GAS-TESTING DEVICES

Various battery-powered pocket-sized devices for the detection of toxic, flammable and oxygen-deficient atmospheres are on the market.

Operating and maintenance instructions provided in the manufacturer's specifications must be strictly adhered to. These electronic testing devices must be approved by the Canadian Standards Association or by Canmet, the Canada Centre for Mineral and Energy Technology with Energy, Mines and Resources Canada, if for use in coal and metal mines.

The NMS MX241 dual-sensor instrument (Plate 5-3) is designed for use in mines and other work environments to assure optimum personal protection against both oxygen deficiency and hazardous levels of methane gas. This small, lightweight, rugged oxygen-methane monitor is particularly suitable for mine rescue teams and fire bosses.

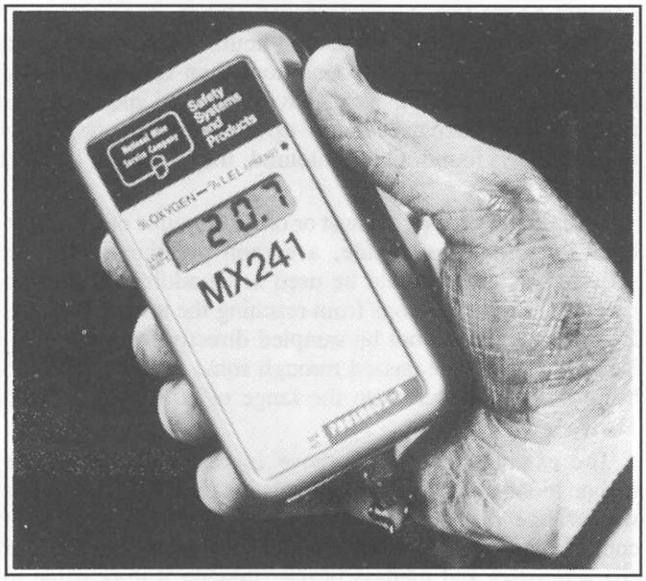


Plate 5-3. NMS MX241 dual sensor gas detector for oxygen and methane.

OXYGEN ANALYSERS

Some oxygen analysers and monitors are designed to measure the amount of oxygen in air. Other instruments measure gases and dissolved oxygen in liquids. These units are a patented polarographic sensor to measure oxygen (Plate 5-4).

Plate 5-4. Polarographic sensor used for measurement of oxygen concentration in atmosphere.

When the oxygen sensor is placed in the environment to be tested the percentage of oxygen is shown directly on the meter. The CALIBRATE control knob to the right of the meter provides fast and direct calibration of the instrument to ordinary room air (20.9 per cent oxygen).

On battery-operated models the fully depressed position of the OFF button is used to check the battery. If the meter needle swings to within the green area on the dial, the batteries are operable. If the reading is to the left of the green area both batteries should be replaced. Any 9-volt transistor-radio battery can be used, but mercury batteries such as Mallory TR-146X or alkaline Duracell batteries are recommended (note: ordinary zinc-carbon batteries may be used for brief periods, but should never be left in the instrument for extended periods or corrosion will result).

The model 60-625 Monitor is specifically designed for worker safety applications and has an audible alarm internally set at 19.5 per cent oxygen.

METHANOMETERS

Operating instructions for the methanometer, illustrated in Plate 5-5, are as follows.

(1) Hold the methanometer in the right hand with the thumb resting on the switch button of the desired measuring range and the third finger on the switch button of the sampling pump.

(2) Place the inlet at the sampling point. Take care that no water or other fluid is drawn into the instrument as damage will occur.

(3) Press the pump switch button and hold it down for at least 3 seconds, then release the button.

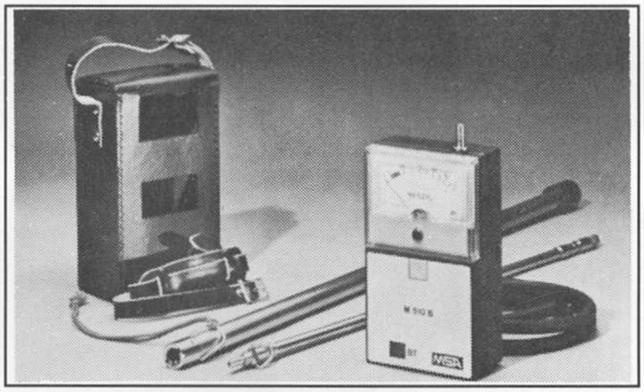


Plate 5-5. Methanometer used for measurement of methane concentration in atmosphere.

(4) Wait for 5 seconds during which time the instrument should be brought into the operating position (approximately 45° angle). Press the switch button for the desired measuring range. The meter needle will first deflect to the left and then move upscale above zero (if methane is present) to a point of maximum value where it will pause momentarily before returning downscale to zero.

(5) The maximum upscale reading corresponds to the methane concentration at the sampling point. If the methane concentration is above 5 per cent, the meter needle will remain in the red portion of the scale for a period of time dependent upon the concentration (note: if a high concentration is indicated, flush the flow system with an adequate quantity of fresh air to remove any residual traces of methane before further tests are made or the electrical zero is checked).

(6) If a sampling tube or probe is to be used with the methanometer, it connects simply by pressing the tube over the inlet fitting. Direct the inlet end to the point to be sampled (make sure that no liquid is drawn into the tube or probe). Sample and measure in the manner previously described, except allow an additional 4 seconds of sampling time for each 1 metre (3 feet) of sampling tube or probe (for example, if the 2-metre sampling tube is used, sample for a minimum of 11 seconds).

Other electronic gas-testing devices are shown in Plates 5-6 and 5-7.

Plate 5-6. Mini CO carbon monoxide indicator.

Plate 5-7. Mini H_2S hydrogen sulphide indicator.

THE BACHARACH MODEL H NATURAL GAS INDICATOR/LEAK DETECTOR

The Bacharach Model H natural gas detector or J-W Gas Pointer (Plate 5-8) is a portable unit for detecting and measuring flammable gas concentrations. The unit operates in two ranges, 0 to 100 per cent of the lower explosive limit and 0 to 100 per cent of the actual concentration of natural gas. In the lower range the Model H is the same as the J-W Sniffer Model G. Detection is by catalytic combustion on a platinum filament; full-scale represents approximately 4 per cent natural gas in air. In the high range measurement is by thermal conductivity from a noncatalytic filament.

The meter dial is easy to read; a two-position valve controls the high and low metering range. Methane is used to calibrate the unit as it is more sensitive to methane than any other hydrocarbon gases. If the indicator has a normal response to the presence of methane it will respond normally to all other combustible gases and vapours.

Plate 5-8. Bacharach Model H natural gas indicator.

CHAPTER 6

FIRE EMERGENCIES AND SAFE FIREFIGHTING PRACTICES

TRAINING OBJECTIVES

Fire, both on surface and underground, is one of the most hazardous emergencies that can arise on a mining operation. Mine rescue teams must be conversant with all aspects of firefighting, from minor fires that are quickly and easily extinguished, to major disasters that may cause widespread damage and possibly loss of life. Fighting fires underground is particularly hazardous and requires a basic knowledge of the principles of mine ventilation. This subject will be treated in a later chapter of this manual; this chapter will cover the broad principles of fire suppression, as they relate to more common fire emergencies on surface.

The objectives of this chapter are to ensure that trainees know and understand the following:

- **Fire behaviour terminology.**
  - Flash point.
  - Fire point.
  - Ignition temperature.
  - Flammable and explosive limits.
  - Vapour density.
- **The basic theory of combustion.**
  - The "Fire Triangle".
  - The "Fire Tetrahedron".
  - The amount of oxygen necessary for free-burning fire.
- **The part played by fuel, oxygen, heat and uninhibited chemical chain reaction in the combustion process.**
  - The influence of fuel-particle size and shape.
  - The influence of above or below normal concentrations of oxygen.
- **The three phases of a fire, and their characteristics.**
  - Incipient phase.
  - Free-burning phase.
  - Smouldering phase.
- **The four classes of fires.**
  - Class A: wood, paper, rubber and plastic.
  - Class B: liquids, greases and gases.
  - Class C: electrical fires.
  - Class D: combustible metals.
- **The basic theory of fire suppression.**
  - Temperature reduction.
  - Fuel removal.
  - Oxygen dilution.
  - Inhibition of chemical chain reaction.
- **The principles and effects of ventilation when fighting fires.**
  - The special dangers of fires in confined areas.
  - Backdraft.
  - The advantages of ventilation.
- **The common types of extinguishing agent.**
  - The operating principle of each type.
  - The advantages of each agent.
  - The limitations of each agent.
- **The various types of portable fire extinguishers.**
  - The operating principles of each type.
  - The horizontal range of each type.
  - The approximate duration of discharge for each type.
  - The rating system for portable fire extinguishers.

Students will be required to demonstrate the ability to select the appropriate extinguisher and suppress Class A and Class B fires.

A glossary of firefighting terms, many of which are used in this chapter, is provided in Appendix 2, and will be a useful reference for the student.

WHAT IS FIRE?

Fire or burning may be described as a form of rapid exidation of a substance and is accompanied by a large release of heat and light energy (the release of heat energy may be so rapid as to cause a violent expansion of the gases produced which is described as an explosion).

Oxidation is the chemical combination of oxygen with another element or compound. This combination is almost invariably accompanied by a release of heat energy. Such a release is known as an exothermic reaction. The amount of heat energy released varies with the elements or compounds with which oxygen combines. Among the highest heat energy releases are those occurring when oxygen combines with carbon, hydrogen, or a compound of both elements.

If the chemical combination with carbon and oxygen is complete carbon dioxide, a colourless gas, is produced. If the combination is with hydrogen and oxygen, water varpour or steam is produced. If the combination includes both carbon and hydrogen and the reaction is complete, then carbon dioxide and water vapour are produced and the resulting smoke is white. If the reaction is incomplete, the the products of combustion are carbon monoxide, carbon dioxide, water vapour, and particles of free carbon which form grey or black smoke.

SOURCES OF HEAT

We know that as the temperature of a substance rises, the motion of the molecules increases and becomes more rapid. Heat, as energy, is a measure of molecular motion in a material. Because molecules are constantly moving, all matter contains some heat regardless of how log the temperature. The speed of the molecules increases when a body of matter is heated. Anything that sets the molecules of a substance in motion produces heat in that material. There are four general sourses of heat energy:

- Chemical heat energy.
- Electrical heat energy.
- Mechanical heat energy.
- Nuclear heat energy.

1. **Chemical Heat Energy:** Chemical heat energy is the rapid oxidation that causes combustion. Substances capable of oxidizing rapidly are known as combustibles. The most common of these materials contain significant amounts of carbon and hydrogen.

   Sufficient heat for combustion is normally achieved when combustible material absorbs heat from an adjacent substance acting as a source of ignition. In some cases, however, certain combustibles are capable of self-generating temperature increase to a point where ignition can occur. This is known as spontaneous ignition. While most organic or carbon-based substances do oxidize and release heat, this process is usually slow enough that the induced heat is dissipated before combustion takes place. Spontaneous ignition is so rapid that combustion does occur.

2. **Electrical Heat Energy:** Electrical energy can cause heat high enough to be the cause of fire through arcing, dielectric heating, induction heating or through heat generated by resistance to the current flow. This last process may be intentional heating, as in the case of filaments or heating elements, or accidental heating, as when electrical "shorts" or overloading occur.

   Static electricity causes an arcing effect between a positively and a negatively charged body when frictional electricity becomes great enough that a spark is discharged from body to body. This spark may not be of adequate duration or generate enough heat to ignite ordinary combustibles. However, it may ignite flammable liquid vapours and gases.

   Lightning has an action similar to that of static electricity. It occurs when one cloud arcs to the ground or to another cloud with an opposite charge. The magnitude of a lightning charge generates sufficient heat in many cases to ignite combustible materials. The high amperage and high voltage potential, although of short duration, can do much structural damage even though fire may not occur.

3. **Mechanical Heat Energy:** One source of mechanical heat energy comes from friction or the resistance to motion of two bodies rubbing together. Another source is derived from the compression of gases. When a gas is compressed, its temperature increases. This can be demonstrated by pumping compressed air into a car tire or tube. As the pressure builds, the tube valve and pump fitting heat up. This can easily be felt by the hand.

4. **Nuclear Heat Energy:** The release of very large quantities of energy from the nucleus of an atom is known as nuclear heat energy. Nuclear energy can be released from the atom by two methods. Nuclear fission is the splitting of the nucleus of an atom. Nuclear fusion is the fusion of the nuclei of two atoms. Controlled release of nuclear energy is finding a wide use in industrial technology.

THE BURNING PROCESS

In re-examining the rapid oxidation process known as combustion, we note that three factors appear to be necessary:

1. A combustible material is needed in
2. The presence of oxygen or an oxidizing agent, with
3. A source of heat sufficient to increase the temperature of the combustible material to its ignition temperature.

These three factors have been incorporated into the simple fire triangle model: Fuel, Oxygen, Heat. (Fig. 6-1.)

Once combustion has been initiated and given an ample supply of fuel and oxygen, the fire can become self-supporting. As the fuel burns, it creates more heat. The increase in heat raises more fuel to its ignition temperature. As the need for more oxygen arises to support combustion, it is drawn into the fire zone. The oxygen in turn increases the heat and more fuel becomes involved. Combustion will continue as long as enough heat is present.

While oxidation is speeding up to the combustion stage, another process is occurring that helps combustion. A chemical decomposition process known as pyrolysis occurs when a substance is exposed to heat. As chemical decomposition takes place, the substance will emit vapours and gases which can form ignitable mixtures with air at certain temperatures.

This chain of reaction and interaction continues until either all the fuel has been consumed, all the oxygen has been used up, or the heat has been dissipated so that the temperature of

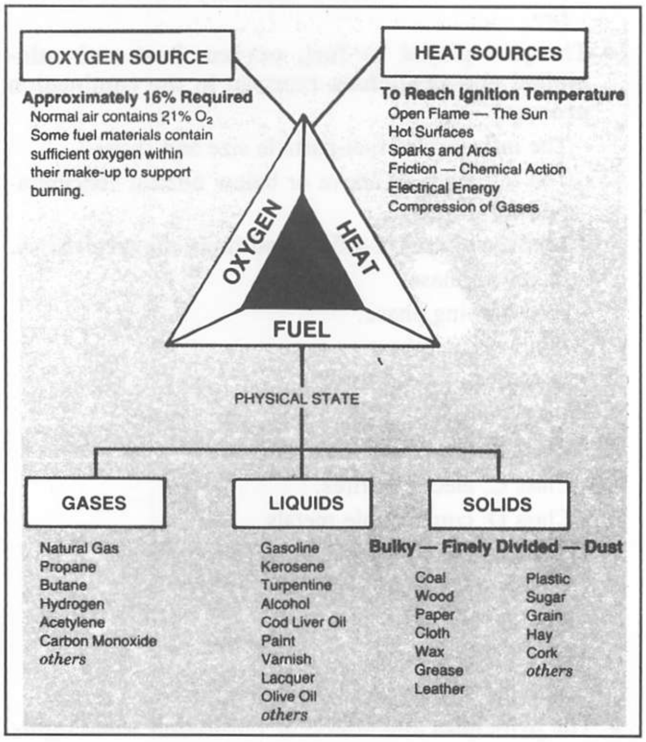


Figure 6-1. The "Fire Triangle."
Courtesy: Fire Academy – J.I. of B.C.

the fuel is lowered below its ignition temperature. This, in essence, states the fundamental method of fire extinguishment — removal of one side of the triangle by:

1. Cooling, to reduce the temperature of the fuel to below its ignition temperature
2. Smothering, to prevent oxygen from reaching the fire by displacing the air with an inert gas, by sealing off within an inert blanket of foam or by smothering the fire in some other way
3. Separation, by removing unburned fuel from the fire by physical or mechanical means

TABLE 6
SOME EXAMPLES OF EXPLOSIVE LIMITS, FLASH POINTS, AND IGNITION TEMPERATURES

Fuel	**Explosive Limit** *per cent*	**Flash Point** *°F*	**Ignition Temperature** *°F*
Acetylene	2.5-81	—	571
Carbon monoxide	12.5-74	—	1 128
Ether	1.9-48	-49	356
Gasoline	1.4- 7.6	-45	536
Lube oil	—	300-450	500- 700
Methane	5.0-15	—	1 202
No. 1 fuel (stove oil)	0.7- 5	100	900-1 070
Propane	2.2- 9.5	—	871

The fire tetrahedron is four-sided figure with the four sides representing fuel, heat, oxygen and uninhibited chemical chain reaction. (Fig. 6-2).

When a source of fuel, a source of heat and oxygen combine, fire is the result. In the chemical reaction that takes place, there are many by-products. Some of the by-products include carbon monoxide (CO), carbon dioxide (CO_2) and sulphur dioxide (SO_2).

These by-products are produced by heat in the form of vapours that will combine with oxygen and burn, thus feeding the chemical chain reaction of combustion and contributing to the chain that expands the fire.

To the three methods of extinguishment in the fire triangle, a fourth method is added for the fourth side of the tetrahedron:

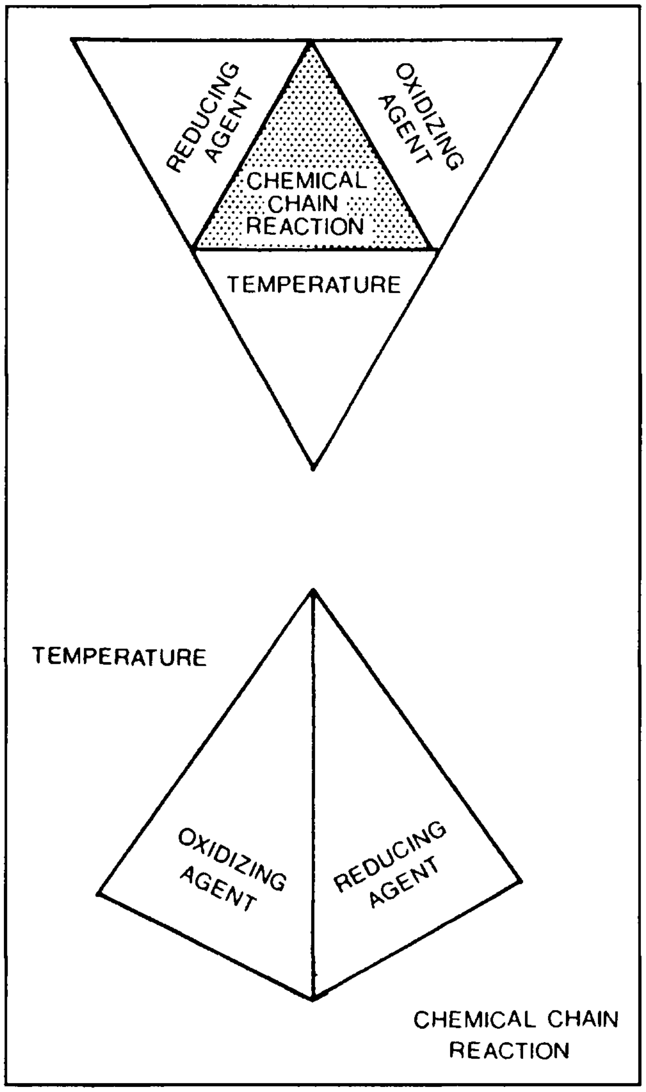


Figure 6-2. Fire Tetrahedron.
Courtesy: Fire Academy — J.I. of B.C.

FACTORS AFFECTING FIRE BEHAVIOUR

Solid fuels have definite size and shape. The surface area of a solid fuel in relation to its mass is a primary consideration for the firefighter. The larger the surface area for a given mass, the more rapid the heating of the fuel and the process of pyrolysis.

The physical position of a solid fuel is also important to fire department personnel. If a solid fuel is in a vertical position, the fire will spread more rapidly than if it is in a horizontal position. This is because of increased heat transfer through conviction, direct flame contact, conduction and radiation. (These terms will be discussed in detail in subsequent sections.)

LIQUID FUELS

Liquid fuels have physical properties that incrase the difficulty of extinguishment and the hazards to personnel. Liquids will assume the shape of their container. When a spill occurs, the liquid will assume the shape of the ground and will flow and accummulate in low areas.

The density of liquids in relation to water is known as specific gravity. Water is given a value of one. Liquids with a specific gravity less than one are lighter than water. Those with a specific gravity greater than one are heavier than water (most flammable liquids have a specific gravity of less than one). As mentioned earlier, hydrocarbon liquids, as a rule, will not mix with water.

GASES

Gases tend to assume the shape of their container but have no specific volume. (Fig. 8.) If the vapour density of a gas is such that it is less dense than air (air is given a value of one), it will rise and tend to dissipate. If a gas or vapour is heavier than air, it will tend to hug the ground and travel by terrain and wind.

PHASES OF FIRE

Fires may start regardless of the time of day. Fires are usually discovered and suppressed if they occur in an occupied area. If a fire happens in a closed or deserted building, however, it may go undetected until it causes major damage. When a fire starts in a building, situations develop that require carefully thought-out and executed ventilation procedures if further damage is to be prevented and danger reduced. This type of fire can best be understood by examining its three progressive phases.

A firefighter may be confronted by one or all of the folowing phases of fire at any time. Knowledge of these phases is important for understanding ventilation and firefighting principles.

1. **Incipient Phase:** In this first phase, the oxygen in the air has not been reduced significantly. The fire is emitting water vapour, carbon dioxide, sulphur dioxide, carbon monoxide and other gases. Heat is being generated and the amount will increase as the fire progresses. Although the temperature in the room may be only slightly increased, the fire may be producing a flame temperature in excess of 537°C (1,000°F). Incipient fires initiate heat, smoke and flame damage. (Fig. 6-3.)

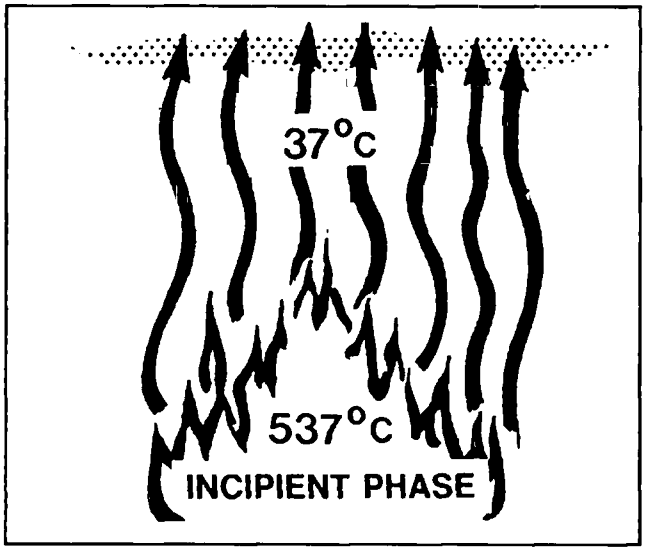


Figure 6-3.
Courtesy: Fire Academy — J.I. of B.C.

2. **Free-burning Phase:** During the second phase of burning, oxygen-rich air is drawn into the flame as convection carries the heat to the top of the confined area. From the top downward, the heated gases expand laterally, forcing the cooler air to lower levels and eventually igniting all the combustible material in the upper levels of the room. (Fig. 6-4.)

   This heated air is one of the reasons that firefighters are taught to keep low and use protective breathing equipment. One breath of this superheated air can sear the lungs.

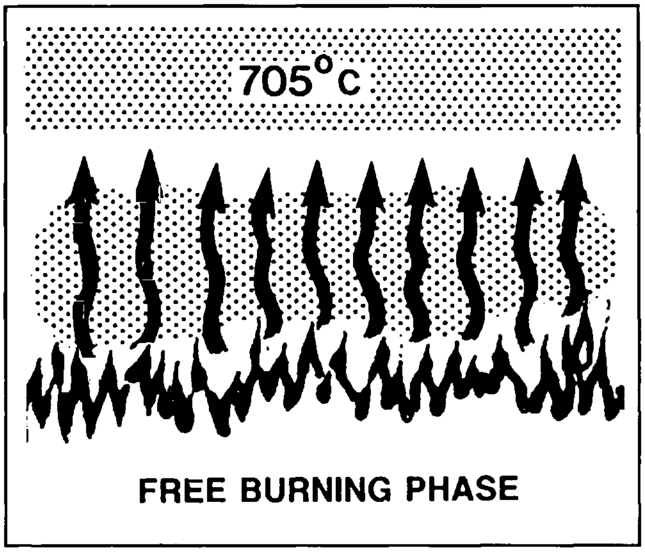


Figure 6-4.
Courtesy: Fire Academy — J.I. of B.C.

   At this point, the temperature in the upper regions can exceed 700°C (1,300°F). As the fire progresses through the latter stages of this phase, it continues to consume the free oxygen until it reaches the point where there is insufficient oxygen to react with the fuel. The fire is then reduced to the smoldering phase.

   Free-burning fires burn rapidly, using up oxygen and building up heat.

3. **Smouldering Phase:** In the third phase, there may be no detectable flame if the room or building is sufficiently airtight. Burning is reduced to glowing embers. The area becomes filled in its entirety with dense smoke and gas. The smoke and gas may be forced by pressure through all cracks. The fire will continue to smoulder at a temperature well over 537°C (1,000°F). (Fig. 6-5.)

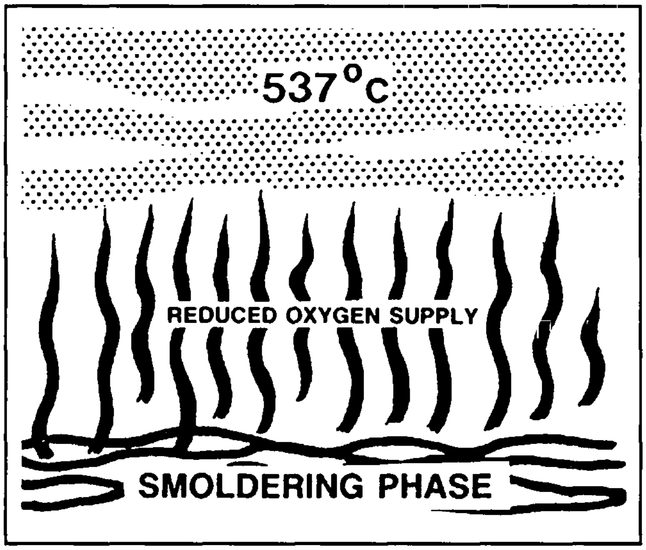


Figure 6-5.
Courtesy: Fire Academy — J.I. of B.C.

The intense heat will have vapourized the lighter fuel fractions such as hydrogen and methane from the combustible material in the room. These fuel gases will be added to those produced by the fire and will further increase the hazard to the firefighter and create the possibility of a backdraft situation.

In the smouldering phase, the oxygen content in the air is less than 15 percent and only needs an increase in oxygen to burn rapidly or explode.

Flashover: It was originally thought that flashover was caused by the release of combustible gases in the early stages of the fire. These gases were believed to collect at the ceiling of a room or building and mix with air until they reach their flammable range, suddenly igniting and causing flashover. While this may occur, it precedes flashover. Flashover is the simultaneous ignition of all the contents of a fire area.

The cause of flashover is attributed to the gradual heating of all the contents of the fire area to their ignition temperatures. When this point is reached, simultaneous ignition occurs and fire erupts throughout the entire area.

Backdraft: Firefighters responding to a confined fire that is late in the free-burning stage or in the smouldering phase risk causing a backdraft or smoke explosion if care is not taken in opening the structure.

Burning is incomplete in the smouldering phase of a fire because there is not a sufficient amount of oxygen to sustain it. The heat from the free-burning phase remains, however, and the unburned carbon particles and other flammable products of combustion are ready to burst into almost instantaneous combusion when more oxygen is available.

Proper ventilation releases smoke and the hot unburned gases from the upper areas of the room or structure. Improper ventilation at this time supplies the dangerous missing link — oxygen. As soon as the needed oxygen rushes in, the stalled combustion resumes. It can be devastating in its speed, truly qualifying as an explosion.

Warning signs of a possible backdraft situation (Fig. 6-6) may include the following:

- Smoke under pressure
- Black smoke becoming dense gray yellow
- Confident and excessive heat
- Little or no visible flame
- Smoke leaving the building in puffs or at intervals
- Smoke-stained windows
- Muffled sounds
- Sudden rapid movement of air inward when opening is made

Remember, proper ventilation can reduce the level of danger posed by this type of condition.

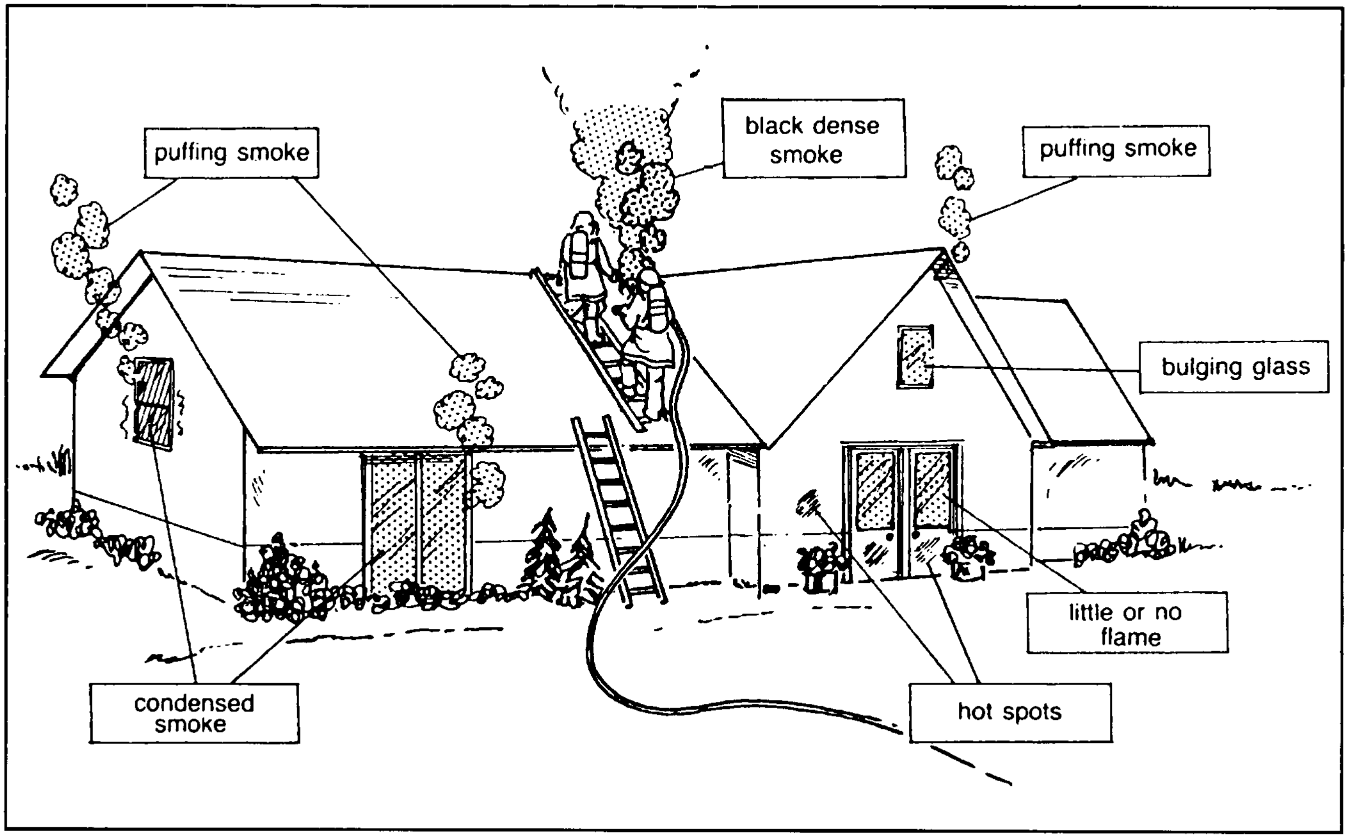


Figure 6-6. Watch for backdraft. *Courtesy: Fire Academy — J.I. of B.C.*

THE IMPORTANCE OF VENTILATION IN FIRE SUPPRESSION

VENTILATION APPLIED TO FIREFIGHTING

Ventilation, applied to firefighting, is the planned and systematic release and removal of heated air, smoke, and toxic gases from a confined area and the replacement of these products of combustion with a supply of cooler fresh air. Proper ventilation cannot be accomplished haphazardly and one cannot rely solely upon knowledge gained from practical experience in actual fire situation since no two fires are alike. Ventilation must, therefore, be recognized as a technical subject and one must approach the study of ventilation theory and practices from this basic point of view.

OBJECTIVES AND ADVANTAGES

The major objectives of a firefighting force are to reach the scene of the fire as quickly as possible, rescue trapped victims, locate the fire, and apply suitable extinguishing agents with a minimum of fire, water, smoke, and heat damage. Ventilation during firefighting is definitely an aid to the fulfillment of these objectives. To effectively and adequately perform some of these objectives, it often becomes necessary to safely get inside a structure. This problem emphasizes one reason why all fire companies should be equipped with adequate respiratory protection for the firefighters. Although fire ventilation provides better breathing conditions within a structure, it does not remove all hazards and dangerous gases. The application of water fog into a heavily charged heated area may collect carbon particles from the smoke and dissipate smoke and gases from the area but it does not eliminate the possible need for respiratory protection. When proper ventilation is accomplished to aid fire control, there are certain advantages that may be obtained from its application. Some advantages of ventilation are:

AIDS LIFE SAVING AND RESCUE

Proper ventilation simplifies and expedites the rescue of victims by removing smoke and gases which endanger occupants who are trapped or unconscious, and by making conditions safer for firefighters.

SPEEDS ATTACK AND EXTINGUISHMENT

The removal of smoke, gases and heat from a building permits firefighters to more rapidly locate the fire and proceed with its extinguishment. Proper ventilation of a building further enables firefighters to determine the path or travel of the fire and to take proper steps for its control.

REDUCES THE DANGER OF BACKDRAFT OR SMOKE EXPLOSION

When sufficient heat is confined in an area, the temperatures of combustible materials rise to their ignition points. These materials will not ignite, however, unless sufficient oxygen is available to support combustion. In this situation, a very dangerous condition exists because the admittance of an air supply (which provides the necessary oxygen) is all that is needed to change the overheated area into an inferno. This sudden ignition is often referred to as a backdraft. In order to prevent this critical situation from occurring, top ventilation must be provided to release superheated fire gases and smoke.

Firefighters must be aware of this explosion potential and must proceed cautiously in areas where excessive amounts of heat have accumulated. During firefighting or rescue operations, doors should be opened slightly and carefully so they may be closed quickly, if necessary, to shut off the air supply to extremely hot areas.

Situations which create a backdraft are confinement and intense build-up of heated gases in an atmosphere being depleted of oxygen. Proper ventilation is a procedure whereby these heated gases can be released with a minimum of additional damage to the structure.

REDUCES MUSHROOMING

Heat, smoke, and fire gases will travel upward to the highest point in an area due to convection until they are trapped by a roof or ceiling. As they are trapped and begin to accumulate they bank down and spread laterally to involve other areas of the structure. This phenomenon is generally termed mushrooming.

Proper ventilation of a building during a fire reduces the possibility of mushrooming. It tends to draw the fire to a point by providing an escape for the rising heated gases.

MAKES FIREFIGHTING EASIER

Proper ventilation not only reduces the danger of asphyxiation, it also reduces the obstacles which hinder firefighters while they perform fire extinguishment, salvage, rescue, and overhaul procedures, by enhancing vision and removing the discomfort of excessive heat.

REDUCES FIRE AND WATER DAMAGE

Rapid extinguishment of a fire reduces not only the actual fire damage but also water damage. Proper ventilation assists in making this damage reduction possible. One method of ventilation that may prove advantageous is applying water in the heated area in the form of water fog or spray. The gases and smoke may be dissipated, absorbed, or expelled by the rapid expansion of the water when it is converted into steam.

REDUCES SMOKE AND HEAT DAMAGE

Smoke may be removed from burning buildings by controlling heat currents, by collecting carbon in the condensed steam, by dissipating smoke through the expansion of water as it is turned into steam, or by mechanical processes. Mechanical processes include blowers, exhaust fans, and smoke ejectors. Regardless of the method used, ventilation reduces smoke damage because fuel vapors and carbon particles are removed.

PERMITS PROMPT SALVAGE OPERATIONS

When smoke, gases, and heat are removed from a burning building, the fire can be more quickly confined to an area. This accomplishment will permit effective salvage operations to be initiated even while fire control is being accomplished. Very little merchandise is saved when covers are placed over water-soaked, smoke-filled materials, therefore, it is imperative that salvage operations be started as soon as possible.

Helps Provide Confinement

When an opening is made in the upper portion of a building during ventilation, a chimney effect is created which draws air currents from throughout the building in the direction of the opening. For example, if this opening is made directly over the fire, it will tend to localize the fire. If it is made elsewhere, it may contribute to the spread of the fire.

CONSIDERATIONS AFFECTING DECISION TO VENTILATE

The requirements for a plan of attack must be considered before a fire officer directs or orders a ventilation operation. He should first make a series of decisions pertaining to ventilation needs. These decisions will, by the nature of fire situations, fall into the following order:

First Decision

Is there a need for ventilation at this time?

The answer to this question must be based upon the heat, smoke, and gas conditions within the structure and the life hazard.

Second Decision

Where is ventilation needed?

The answer to this question involves construction features of the building, contents, exposures, wind direction, extent of the fire, location of the fire, top or vertical openings, and cross or horizontal openings.

Third Decision

What type of ventilation should be used?

The answer to this question may be derived from a fire officer's knowledge of the following three methods of ventilation:

(1) Providing an opening for the passage of air between interior and exterior atmospheres;

(2) Using the application of water fog and the expansion of water into steam to displace contaminated atmospheres; and

(3) Using forced air ventilation.

When a fire officer determines the need for ventilation he should also consider the precautions that may be necessary for the control of the fire and the safety of his men. There is a need for protective breathing equipment for respiratory protection and charged hose lines for firefighting, especially during the ventilation process. The possibilities of fire spreading throughout a building and the dangers of exposure fires are always present.

VISIBLE SMOKE CONDITIONS

Smoke conditions will vary according to how burning has progressed. A free-burning fire must be treated differently than one which is in the smoldering stage. A fire which is localized is frequently mistaken for a large generalized fire because of the large volume of smoke. Smoke accompanies most ordinary forms of combustion, and it differs greatly with the nature of the substances of materials being burned. The density and color of the smoke is in a direct ratio to the amount of suspended particles. A fire that is just starting and is consuming wood, cloth, and other ordinary furnishings will ordinarily give off gray-white or blue-white smoke of no great density. As the burning progresses, the density may increase, and the smoke may become darker because of the presence of large quantities of carbon particles.

Black smoke is usually the result of burning rubber, tar, roofing, oil, or other flammable liquids. It has been said that brown smoke may indicate nutrous fumes and that gray-yellow smoke is a danger signal of approaching backdraft. A firefighter should remember that the materials which smoke contains can only be determined by chemical analysis. ALTHOUGH THE COLOR OF THE SMOKE MAY BE OF SOME VALUE IN DETERMINING WHAT IS BURNING, SMOKE COLOR IS NOT ALWAYS A RELIABLE INDICATOR. It is sometimes quite easy for firefighters to classify what is burning by distinctive odors, especially during the early stages of the fire. Smoke from burning rubber, rags, pine wood, feathers or grass all have a characteristic odor and will permit a firefighter to determine what kind of material is burning. As the smoke grows more dense and the firefighter is exposed to greater quantities, irritation to the nasal passages soon decreases an ability to recognize odors.

One proven method by which smoke and heat may be removed from a burning building is by opening the structure at a strategic place to permit the smoke and heat to escape. This method may be applied to top or vertical ventilation as well as to cross or horizontal ventilation. Although many situations and conditions frequently eneountered in vertical ventilation are also common in horizontal ventilation, specific features are discussed here which influence top or vertical ventilation.

THE BUILDING INVOLVED

Knowledge of the building involved is a great asset when making decisions concerning ventilation. Building type and design are the initial factors to consider in determining whether horizontal or vertical ventilation should be accomplished. The number and size of wall openings, the number of stories, staircases, shafts, dumbwaiters, ducts, roof openings, the availability and involvement of exterior fire escapes and exposures are determining factors. Building permits that are issued in one's own city may enable the fire department to know when buildings are altered or subdivided. Checking these permits will often reveal information concerning heating, ventilating, and air-conditioning systems; the type of roof construction; roof openings; and avenues of escape for smoke, heat and fire gases. The extent to which a building is connected to adjoining structures also has a bearing on the decision. In-service company inspection and pre-fire planning may provide more valuable and detailed information.

FIRE CONTROL

BEFORE VENTILATING A BUILDING, A FIRE OFFICER MUST PROVIDE MANPOWER AND ADE-

QUATE FIRE CONTROL FACILITIES BECAUSE THE FIRE MAY IMMEDIATELY INCREASE IN INTENSITY WHEN THE BUILDING IS OPENED. These facilities should be provided for both the building involved and other exposed buildings. As soon as the building has been opened to permit hot gases and smoke to escape, the next requirement is to reach the seat of the fire for extinguishment. Entrance should be made into the building as near the fire as possible, if wind direction will permit. It is at this opening that charged hose lines should be in readiness in case of violent burning or an explosion. Charged lines should be made available at other points where openings can be made. Thus, if the fire is at the rear of the building, hose lines may also be required at the front. Charged lines will also be required to protect buildings that are likely to be endangered because of their exposure to the one involved.

LOCATION OF THE FIRE

In most instances ventilation should not be carried out until the location of the fire is established. Opening for ventilation purposes before the fire is located may spread the fire throughout areas of the building that would not otherwise have been affected. Smoke that is coming out of the top floor does not always indicate a fire on that floor since it may be on a lower floor or even, perhaps, in the basement. Likewise, smoke that is gently flowing from an opening is not necessarily close to the seat of the fire. Obviously, extensive roof ventilation may be impractical or extremely dangerous if the location of the fire is such that vertical ventilation will draw the fire into parts of the building which are not involved.

EXTENT OE THE FIRE

The fire may have travelled some distance throughout a structure by the time firefighting forces arrive, and consideration must be given to the extent of the fire, as well as to its location. The severity and extent of the fire usually depend upon the kind of fuel, the time it has been burning, installed fire protection devices, and the degree of confinement of the fire. The phase to which the fire has progressed is a primary consideration in determinging ventilation procedures. Some of the ways by which vertical extension occurs are as follows:

- Through stairwells, elevators, and shafts by direct flame contact or by convected air currents.
- Through partitions and walls and upward between the walls by flame contact and convected air currents;
- Through windows or other outside openings where flame extends to other exterior openings and enters upper floors;
- Through ceilings and floors by conduction of heat through beams, pipes, or other objects that extend from floor to floor;
- Through ceilings and floors by direct flame contact;
- Through floor and ceiling openings where sparks and burning material fall through to lower floors; and
- By the collapse of floors and roofs.

SELECTING THE PLACE TO VENTILATE

The ideal situation in selecting a place to ventilate is one in which firefighters have prior knowledge of the building and its contents. There is no rule of thumb in selecting the exact point at which to open a roof except "as directly over the fire as possible". Many factors will have a bearing on where to ventilate. Some of them are:

- The availability of natural openings such as skylights, ventilator shafts, monitors, and hatches.
- Location of the fire and the direction which the chief officer wishes it to be drawn;
- Type of construction;
- Wind direction; and
- The extent of progress of the fire and the condition of the buildings and its contents.

VERTICAL VENTILATION PROCEDURE

After the fire officer has considered the type of building involved, the location and extent of the fire, moved manpower and tools to the roof, observed safety precautions, and has selected the place to ventilate, he has still not completed the operation. Top-level ventilation involves all of these factors plus the following precautions and procedures which the officer in charge must consider and practice if he is to be successful in accomplishing top-level ventilation:

- Co-ordinate with ground and attack companies;
- Observe the wind direction with relation to exposures;
- Note the existence of obstructions or weight on the roof;
- Secure a life line to the roof as a secondary means of escape;
- Utilize natural roof openings whenever possible;
- Cut a large hole if one is required, rather than several small ones;
- Exercise care in making the opening so that main structural supports are not cut;
- Work with the wind at the back or side to provide protection to the operators while cutting the roof opening;
- Guard the opening to prevent personnel falling into the building; and
- Extend a blunt object through the opening to break out the ceiling.

OPENING ROOFS

In order to properly ventilate a roof, the firefighter must understand the basic types and designs of roofs.

Many designs and shapes of roof styles are used, and their names vary in each locality. Roof coverings may be wood shingles, composition shingles, composition roofing paper, tile, slate, or a built-up tar and gravel surface. The roof covering is the exposed part of the roof, and its primary purpose is to afford protection against the weather. The selection of a proper roof covering is important from a fire protection standpoint because it may be subjected to sparks and blazing brands if a nearby building should burn. A study of the more common types of roofs and the manner in which their construction affects opening procedures is necessary to develop effective vertical ventilation. The firefighter is concerned with three prevalent types of roof construction: flat, pitched, and arched styles. Buildings may be constructed with a combination of roof designs including these or other types, but an understanding of these three basic types is adequate for the purposes discussed in this manual. Some of the more common styles are the flat, gable, gambrel, shed, hip, mansard, dome, lantern, and butterfly.

PRECAUTIONS AGAINST UPSETTING ESTABLISHED VERTICAL VENTILATION

When vertical ventilation is accomplished, the natural convection of the heated gases creates upward currents which draw the fire and heat in the direction of the upper opening. Firefighting teams take advantage of the improved visibility and less contaminated atmosphere to attack the fire at its lower point. If the "stack effect" is interrupted, the heat, smoke, and steam back up, hampering extinguishment efforts. Stack effect, is the vertical natural air movement throughout a building. The magnitude of stack effect is determined by the differences in temperature and the densities between the air inside and outside the building. Some common factors that can destroy the effectiveness of ventilation are as follows: improper use of forced ventilation; breakage of glass; improperly directed fire stream; breakage of skylights; an explosion; a burn through; and additional openings between the attack team and the upper opening.

Elevated streams are frequently used to cut down sparks and flying brands from a burning building or to reduce the thermal column of heat over a building. When elevated streams are projected downward through a ventilation opening or used to reduce the thermal column to a point where ventilation is hindered, they either destroy or upset the orderly movement of fire gases from the building. An upset of this nature can materially affect firefighters who may be working at various levels on floors below. Elevated streams, which are being operated closely above ventilated openings, should be projected slightly above the horizontal. In this position they will help cool the thermal colomn and extinguish sparks. The movement of the stream may even increase the rate of ventilation.

Vertical ventilation cannot be the solution to all ventilation problems for there may be many instances where its application would be impractical or impossible. Only prompt and accurate size-up, based on a thorough understanding of the many variables which affect, or are affected by, ventilation can provide the answer to the following two questions:

(1) Is ventilation required?

(2) What type is most appropriate in this instance?

In addition to selecting the method of ventilation, a fire officer must determine how, when, and where it will serve its most useful purpose. A discussion of some of the factors that influence horizontal ventilation follows.

Building type and design are the initial factors which must be considered in determining whether horizontal or vertical ventilation should be accomplished. Type and design features include the number and size of wall openings, the number of stories, and the availability and involvement of exterior fire escapes, and exposures. Directly related to these are protective coverings of the openings, the direction in which the openings face, and the wind direction.

HORIZONTAL VENTILATION

Structures which lend themselves to the application of horizontal ventilation include:

- Residential type buildings in which the fire has not involved the attic area;
- Buildings with windows high up the wall near the eaves;
- The attics of residential type buildings which have louver vents in the walls;
- The involved floors of multi-storied structures; and
- Buildings with large unsupported open spaces under the roof in which the fire is not contained by fire curtains and in which the structure has been weakened by the effects of burning.

Many of the aspects of vertical ventilation also apply to horizontal ventilation. A different procedure must be followed in ventilating a room, a floor, a cockloft, an attic, or basement. The procedure to be followed will be influenced by the location and extent of the fire. Some of the ways by which horizontal extension occurs are as follows:

- Through wall openings by direct flame contact or by convected air;
- Through corridors, halls, or passageways by convected air currents, radiation, and flame contact;
- Through open space by radiated heat or by convected air currents;
- In all directions by explosion of flash burning of fire gases, flammable vapors, or dust;
- Through walls and interior partitions by driect flame contact; and
- Through walls by conduction of heat through beams, pipes, or other objects that extend through walls.

WEATHER CONDITIONS

Weather conditions are always a primary consideration in determining the proper ventilation procedure. Under certain circumstances, when there is no wind, cross ventilation is less effective since the force which removes the smoke is absent. In other instances cross ventilation cannot be accomplished due to the danger of wind blowing toward an exposure or feeding oxygen to the fire. The wind plays an important role in ventilation. Its direction may be designated as windward or leeward.

EXPOSURES

Since horizontal ventilation does not normally release heat and smoke directly above the fire, some routing is necessary. Firefighters should, therefore, be aware of internal exposures as well as external exposures. The routes by which the smoke and heated gases would travel to the exit may be the same corridors and passageways which occupants will be using for evacuation. Thus, the practice of horizontal ventilation without first considering occupants and rescue procedures may block the escape of occupants. The theory of horizontal ventilation is basically the same as that of vertical ventilation inasmuch as the release of the smoke and heat is an aid in fighting the fire and reducing damage.

Outside exposures include those previously mentioned plus those which are peculiar to horizontal ventilation. Since horizontal ventilation is accomplished at a point other than at the highest point of a building, there is the constant danger that the rising heated gases will ignite that portion of the structure which they contact when released. They may ignite eaves of adjacent structures, or be drawn into windows above their liberation point. Unless for the specific purpose of aiding in rescue, a building should not be opened until charged lines are in place at the windward attack entrance point, at the intermediate point where fire might be expected to spread, and in positions to protect other exposures.

PRECAUTIONS AGAINST UPSETTING ESTABLISHED CROSS VENTILATION

The opening of a door or window on the wrong side of a building may reverse air currents and drive heat and smoke back upon firefighters. Opening doors and windows between the advancing firefighting crews and the established ventilation exit point will block the intake of fresh air.

FORCED VENTILATION

Ventilation has thus far been considered from the standpoint of the natural flow of air currents, the currents created by fire, and the effect of fog streams. Forced ventilation is accomplished by blowers, fans, or fog streams. The fact that forced ventilation is effective and can be depended upon for smoke removal when other methods are not adequate proves its value and importance.

THE APPLICATION OF WATER FOG AS AN AID TO VENTILATION

Field experience and studies have conclusively demonstrated that application of water as a spray stream possesses great merit for the control of certain types of fires. The speed by which a given volume of water will absorb heat is in proportion to the amount of water surface that is exposed, and, likewise, its ability to attract or collect the carbon, tar, and ash particles is also increased. As these water particles absorb heat from the heated area the water is converted into steam, and the expansion that takes place may materially aid ventilation.

The use of water fog in fire extinguishment and in ventilation requires a special technique of operation. The mere fact that firefighters have a good fog nozzle, which supplies a protective curtain, does not enable them to advance, helter-skelter into a heavily charged area and expect to do an effective ventilating and extinguishing job. When water fog is used for ventilating and extinguishing purposes, the degree of effectiveness depends upon how, where, and when the fog stream is applied.

Any jet of water, as it passes through the air, causes air turbulence about the stream. The amount of turbulence is influenced by the space occupied by the stream. A fog stream will entrain a great volume of air within and near the space occupied by the pattern and create air currents which can remove a great deal of smoke. Consequently, fog streams, when projected through a door or window, will move large volumes of air in the direction toward which the stream is projected. This method may be used as a means of ventilation.

When using a fog stream in an enclosed area, caution must be exercised to assure an opening to permit the release of expanded steam. This will prevent the heated gases and steam from coming back and endangering the nozzleman.

SOME ADVANTAGES OF FORCED VENTILATION

The value of mechanical ventilation may be further realized when, in order to protect human life it becomes necessary to rid premises or areas of an undesirable atmosphere. Even though fire may not be a factor, contaminated atmospheres must be rapidly and thoroughly ejected. Forced ventilation, if not the only means of clearing a contaminated atmosphere, is always a welcome addition to normal ventilation. Some of the reasons for employing mechanical or forced ventilation are indicated in the following list:

- It insures more positive control;
- It supplements natural ventilation;
- It speeds the removal of contaminants, facilitating more rapid rescue under safer conditions;
- It may be used where other methods fail;
- It reduces smoke damage; and
- It promotes good public relations.

SOME DISADVANTAGES OF FORCED VENTILATION

If mechanical or forced ventilation is misapplied or uncontrolled, it can cause a great deal of harm. Forced ventilation requires considerable supervision because of the mechanical force that is behind it. Some of the disadvantages of forced ventilation are indicated in the following list:

- It can move fire along with the smoke and extend it to lateral areas;
- It can introduce air in such great volumes that it can be the cause of a fire spreading;
- It is dependent upon power, the interruption of which renders it ineffective;
- It employs additional manpower for its operation; and
- It requires special equipment.

FORCED VENTILATION EQUIPMENT

It is difficult to classify forced ventilation equipment by any particular type. The principle applied is that of moving large quantities of air and smoke. These portable blowers are all powered by electric motors or gasoline-driven engines.

Forced air blowers should always be equipped with explosion-proof motors and power cable connections when used in a flammable atmosphere. Forced air blowers should be shut down when they are moved. Before they are started, be sure that there are not persons near the blades and that clothing, curtains, or draperies are not in a position to be drawn into the fan. Blowers should always be moved by the handles which are provided for this purpose. The discharge stream of air should be avoided because of particles that may be picked up and blown by the venting equipment.

HEAT TRANSFER – HOW FIRE SPREADS

Heat can spread to all points of a structure that are exposed to the heat of the fire. A number of natural laws of physics are involved in the transmission of heat. The Law of Heat Flow specifies that heat tends to flow from a hot substance to a cold one. The colder of two materials in contact will absorb heat until both objects are the same temperature.

Heat can travel through a burning building by one or more of four methods:

(1) Conduction,
(2) Convection,
(3) Radiation and
(4) Direct flame contact.

1. **Conduction:** When two objects are touching one another, heat is transmitted from one to the other through the medium of conduction. Conduction of heat depends on the temperature differences between the two substances and the thermal conductivity of the materials. (Fig. 6-7.)

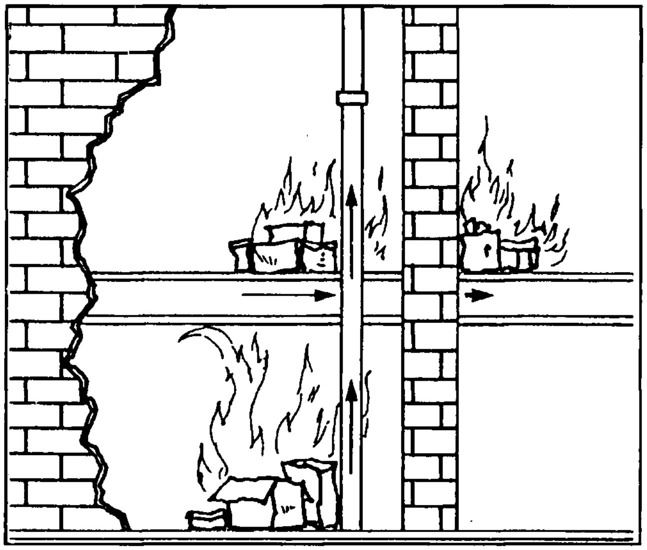


Figure 6-7. Heat transfer by conduction.
Courtesy: Fire Academy – J.I. of B.C.

The greater the heat difference, the more rapid will be the rate of heat transfer. Also, some materials have a higher thermal conductivity rate which permits a greater amount of heat to be conducted to the second object. Aluminum, copper conduct heat very slowly. As a result, an air space between a hot object and a nearby combustible object will greatly reduce the chances of ignition.

2. **Convection:** When heat is transferred through a circulating medium rather than by direct contact, it is transferred by convection. The medium can either be a gas or a liquid that is first heated by conduction from another substance having a higher temperature. Where the gas or liquid contacts another substance of lesser temperature, some of the heat of the medium will be transferred by conduction to the other material. (Fig. 6-8.)

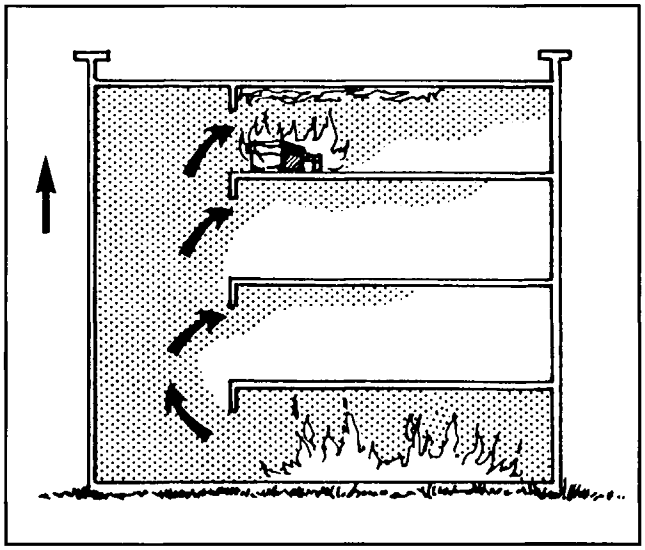


Figure 6-8. Heat transfer by convection.
Courtesy: Fire Academy – J.I. of B.C.

Through convection, heated air, smoke and other fire gases can increase the temperature of an entire building to the point that it bursts into flame – the point of flashover. Heated air in a building will expand and rise, carrying heat to upper levels. For this reason, fire spread due to convection is mostly in an upward direction although air currents can carry heat in any direction. Convection currents are generally the cause of heat movement from floor to floor, from room to room, and from area to area.

3. **Radiation:** Heat energy can travel in waves or rays from one area to another as radiation. Radiant heat, similar to light, travels in a straight line through air, glass, water and transparent plastics to heat combustible materials that are not in direct contact with the heat source. The quality and quantity of heat radiation depends on the temperature of the radiating body and the size of the radiating surface. (Fig. 6-9.)

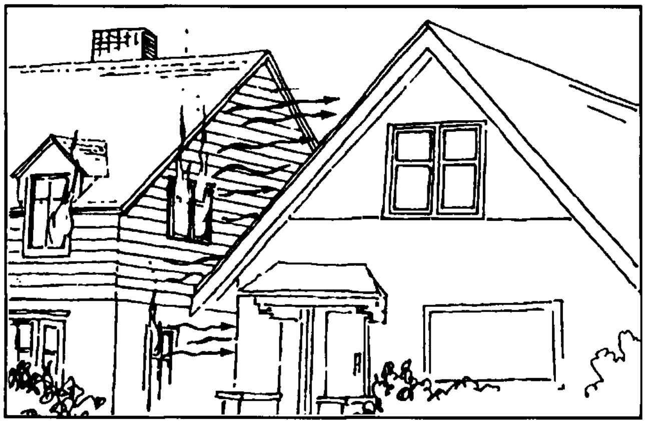


Figure 6-9. Heat transfer by radiation.
Courtesy: Fire Academy – J.I. of B.C.

The ability to absorb radiated heat depends on the kind of surface of the cooler body and the area of the radiating surface of the hotter substance. If the receiving surface is black or dark colored, it will absorb heat readily. If the surface is light in color or shiny and polished, it will reflect much of the heat.

Radiated heat is one of the major sources of fire spread. Its influence demands immediate attention at points where radiation exposure is severe. When fires produce flames of large size and volume, radiation can fall on nearby combustible materials that can become heated to the point of ignition. (The use of water fog and wetting down can help block heat radiation from large fires. The fog reflects the heat rays and breaks up the straight line path of heat radiation.)

4. **Direct Flame Contact:** Another form of heat transfer that is similar to convection is direct flame contact. When a substance is heated to the point where flammable vapours are given off, these vapours may ignite and create a flame. If other flammable materials come in contact with the flame, they may be heated to a temperature where they, too, will ignite and burn. (Fig. 6-10.)

Figure 6-10. Heat transfer by direct contact.
Courtesy: Fire Academy – J.I. of B.C.

THEORY OF FIRE SUPPRESSION

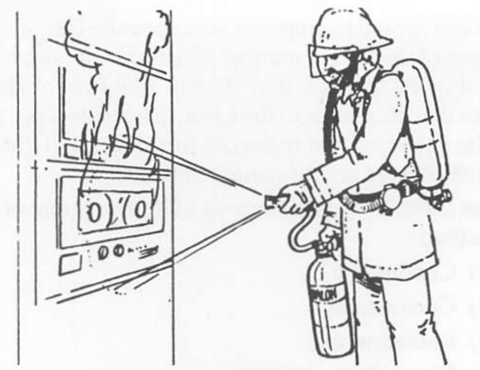
The extinguishment of fire is based on an interruption of one or more of the essential elements in the combustion process. With flaming combustion a fire may be extinguished by:

(1) reducing temperature,
(2) eleminating fuels,
(3) removing oxygen or
(4) stopping the uninhibited chain reaction.

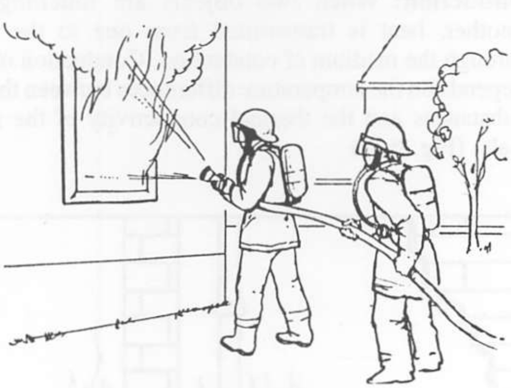
If a fire is in the smouldering mode of combustion, only the first three extinguishment options are feasible.

1. Extinguishment by Temperature Reduction

One of the most common methods of extinguishment is by cooling with water. The process is dependent on cooling the fuel to a point where it does not produce sufficient vapour to burn. A reduction in temperature is dependent on the application of an adequate water flow in proper form to establish a negative heat balance. (Fig. 6-11.)

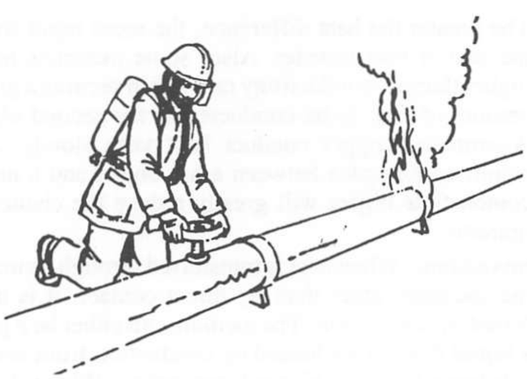


Inhibit the Chain Reaction.



Reduce the Temperature.

Exclude the Oxygen.



Remove the fuel.

Figure 6-11. Four methods used to extinguish fire.
Courtesy: Fire Academy – J.I. of B.C.

In terms of fuel types and vapour production, solid fuels and liquid fuels with high flash points can be extinguished by cooling. Low flash point liquids and flammable gases cannot be extinguished by cooling with water because vapour production cannot be sufficiently reduced.

2. Extinguishment by Fuel Removal

In some cases, a fire is effectively extinguished by removing the fuel source. This may be accomplished by stopping the flow of liquid or gaseous fuel (Fig. 6-11), or by removing solid fuel in the path of a fire. Another method of fuel removal calls for allowing the fire to burn until the fuel is completely consumed.

3. Extinguishment by Oxygen Removal

The method of extinguishment by oxygen removal involves the reduction of oxygen concentration to the fire area. This can be accomplished by separating the oxygen from the fuel (Fig. 6-11) or by introducing an inert gas to the fire that replaces the oxygen. (This method of extinguishment will not work on selfoxidizing materials or on certain metals because they are oxidized by carbon dioxide or nitrogen, the two most common extinguishing agents.)

4. Extinguishment by Chemical Flame Inhibition

Some extinguishing agents, such as dry chemicals and halons, interrupt the chemical chain reaction, resulting in rapid extinguishment. (Fig. 6-11).

CLASSIFICATION OF FIRES AND SUPPRESSION METHODS

The universe of fire types may be divided into four basic categories, represented by Class A, B, C and D type fires. The classification depends largely on the methods of extinguishment and on the combustible materials involved in the fire.

1. **Class** A fires involve solid materials of organic nature in which combustion generally forms glowing embers. This type of fire occurs most often in ordinary combustible materials such as wood, paper, cloth, many plastics and other organic chemical compounds that contain carbon, hydrogen, oxygen and nitrogen. (Fig. 6-12.) Extinguishment of Class A fires requires the cooling effects of water or water solutions, or the coating effects of certain dry chemicals that retard combustion. Class A fires are the most common type of fire.
2. **Class B** fires involve flammable liquids, greases and gases such as gasoline and kerosene. (Fig. 6-13.) The Fire may consume storage facilities consisting of tanks, containers or pressurized vessels containing flammable liquids or gases. The most effective means of extinguishment calls for excluding air (oxygen) from the blaze, inhibiting the release of combustible vapours and interrupting the combustible chain reaction.
3. **Class** C fires involve electrical equipment that is energized — connected to a live source of electrical power. (Fig. 6-14.) Electrical wiring, panel boards, fuse boxes and circuit breakers are subject to short circuits, arcing

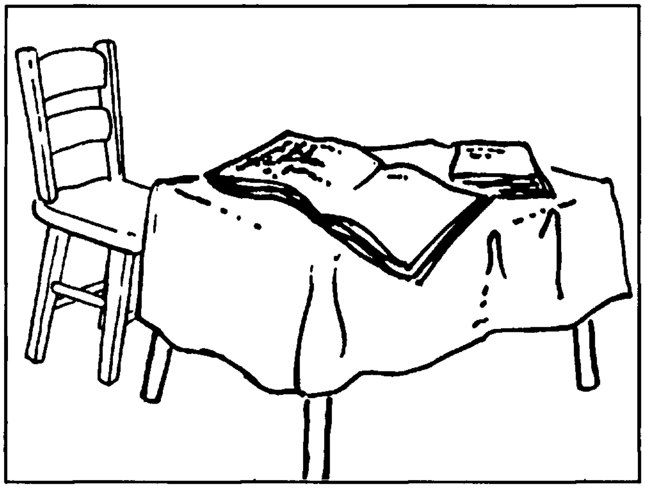


Figure 6-12. Class A fires.
Courtesy: Fire Academy — J.I. of B.C.

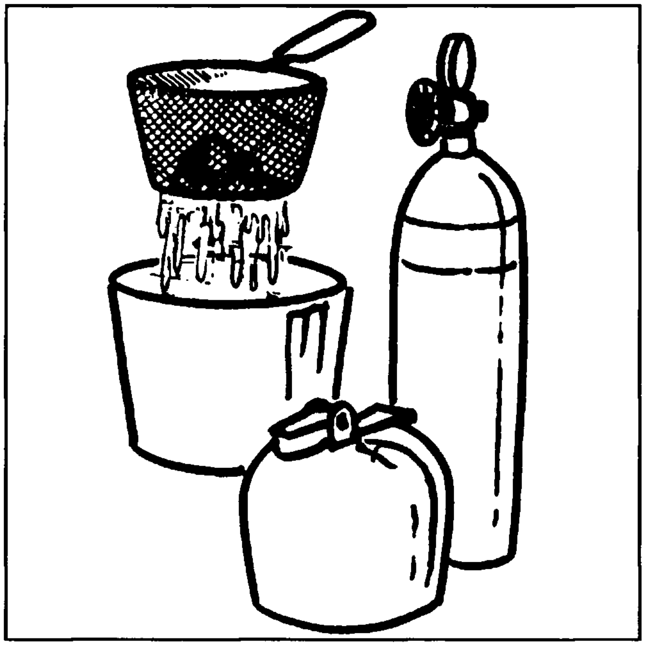


Figure 6-13. Class B fires.
Courtesy: Fire Academy — J.I. of B.C.

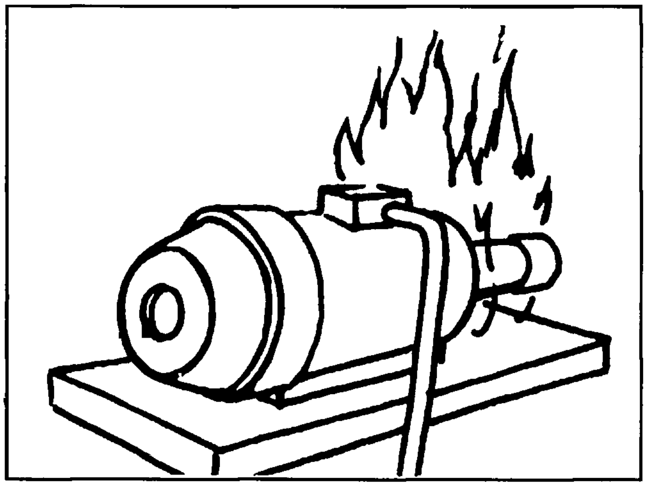


Figure 6-14. Class C fires.
Courtesy: Fire Academy — J.I. of B.C.

and sparking as potential sources of fire. Appliances that use electricity as a source of power such as lamps, irons, power tools and motors may contribute to fires. Safe response requires the use of nonconductive extinguishing agents. Once the electrical equipment has been de-energized, Class A or Class B methods of extinguishment may be used safely, depending on the fuels involved.

4. **Class D** fires involve combustible metals as well as some highly reactive flammable liquids. Combustible metals include several elements such as magnesium, titanium, socium, potassium and zirconium. (Fig. 6-15.) Virtually all metals will burn given the right particle size, temperature and oxygen mixture. Class D fires require a heat-absorbing extinguisher that is not reactive with the burning metal.

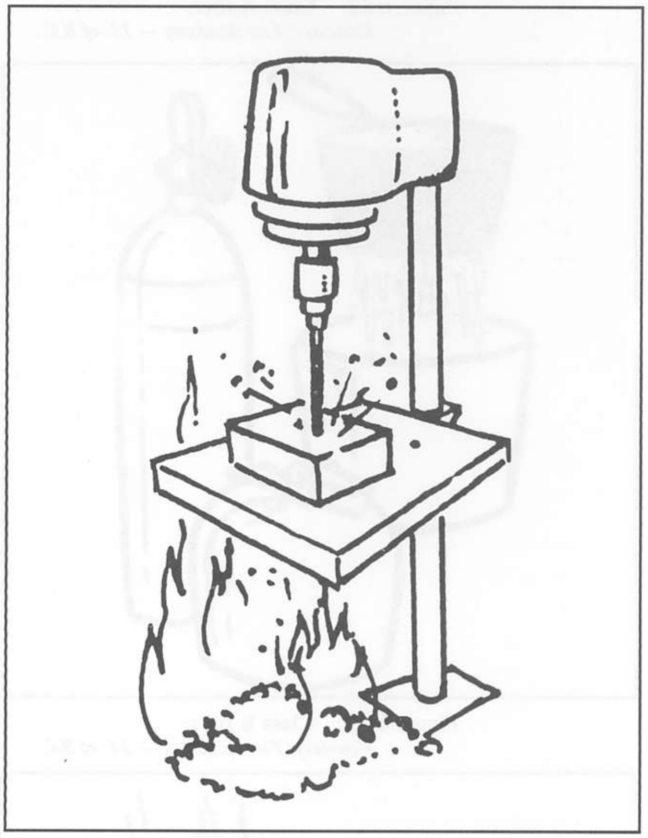


Figure 6-15. Class D fires.
Courtesy: Fire Academy — J.I. of B.C.

PORTABLE FIRE EXTINGUISHERS

The four classes of fire and their hazards define the types of combustible materials involved in each, and the agents that are effective in extinguishing them.

Recommended Marking System (Fig. 6-16)

This method of marking extinguishers is based on tests conducted by the Underwriter's Laboratories, Inc. and the Underwriters' Laboratories of Canada. It is recommended in the interim period prior to conversion to a newer, international pictorial concept.

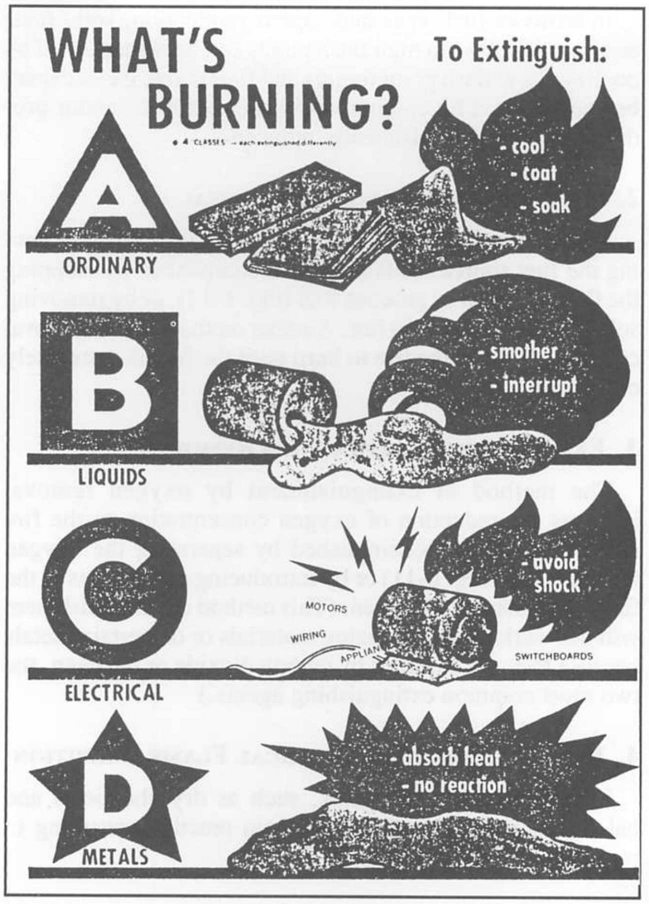


Figure 6-16.

New Marking System

The new marking system combines the uses and non-uses of extinguishers on a single label, and is not in limited use. Picture symbols that depict the types of fires that the extinguisher can and cannot be used on are shown on the label. The non-use is indicated by a line through the symbol. For a view of these symbols see the chapter on Extinguishers in the IFSTA manual, "Essentials of Fire Fighting," Second Edition.

EXTINGUISHER RATING SYSTEM

Quick identification of the **type, class** and **capacity** of portable extinguishers is important. When portable extinguishers are required, there is little time to make decisions, and the decisions must be the correct ones.

When firefighters select an extinguisher, they look at the configuration to identify how to operate the extinguisher and check the rating label to identify the class of fire and the capacity.

UL Rating System

The rating system was developed in the United States by **Underwriter's Laboratories Inc.** to identify the extinguishing potential for each type and size of extinguisher. The number reflects the relative quantity of fire that can be extinguished.

Underwriter's Laboratories of Canada was established in 1921 to perform a similar function.

Knowledge of the rating system is extremely important when selecting the extinguisher that will knock down a fire in the quickest and most effective manner in emergency situations.

The rating system is a combination of letters and numbers that are listed on the faceplate of the extinguisher (Plate 6-1). The letter denotes the class of fire the extinguishing agent is designed for. The numbers indicate the relatively quantity of fire that can be extinguished by a certain size of fire extinguisher.

Extinguishers containing agents suitable for more than one class of fire are identified by multiple symbols in horizontal sequence.

The numeric rating is only intended for Class A and B fires. Class C fires are basically Class A or B fires involving energized electrical equipment. The effectiveness of Class D extinguishers is detailed on the faceplate.

DETERMINATION OF RATINGS

Ratings for Class A and B fires are determined by the time taken for an untrained operator to extinguish a fire of predetermined size and specific materials.

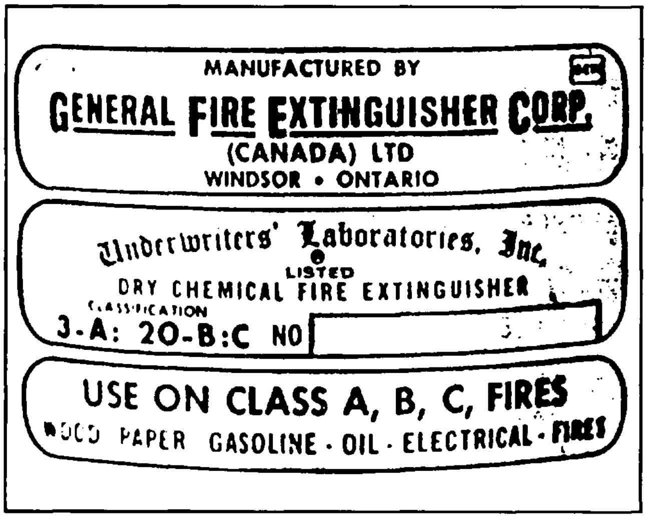
CLASS A RATINGS

Rating: 1-A to 40-A. Determined by extinguishing a wood and excelsior fire of predetermined size. Ratings are based on U.S. gallons.

Examples: 1-A fire requires 4.7 L (1.25 gal.) of water

2-A fire requires 9.5 L (2.5 gal.) of water

A dry chemical extinguisher rated 10-A is equivalent to four 9.5 L (2.5 gal.) water extinguishers.



MANUFACTURED BY
GENERAL FIRE EXTINGUISHER CORP.
(CANADA) LTD
WINDSOR • ONTARIO

Underwriters' Laboratories, Inc.
LISTED
DRY CHEMICAL FIRE EXTINGUISHER
CLASSIFICATION
3-A: 20-B:C NO

USE ON CLASS A, B, C, FIRES
WOOD PAPER GASOLINE · OIL · ELECTRICAL · FIRES

Plate 6-1. Example of extinguisher faceplate.
Courtesy: Fire Academy — J.I. of B.C.

CLASS B RATINGS

Rating: 1-B to 640-B. Determined by extinguishing a n-Heptane (flammable liquid) liquid fire of predetermined size in a square steel pan.

Rating gives an approximate indication of the area in square feet of flammable liquid fire that can be extinguished by an untrained operator.

CLASS C RATINGS

Agents are tested for **electrical nonconductivity.** The agent is only accepted providing it meets a Class A or B rating, or both.

CLASS D RATINGS

Agent tests vary according to the type of combustible metal being tested. When an agent is determined to be safe and effective for a particular metal, detailed instructions are included on the faceplate of the extinguisher.

Examples: Rating 2-A, 6B extinguishes twice as much fire as a 1-A rated extinguisher and six times as much fire as a 1-B extinguisher.

Rating 4-A, 12-B extinguish twice as much fire as a 2-A rated extinguisher and twice as much fire as a 6-B rated extinguisher.

Rating 10-B:C extinguishes ten times the quantity of fire as a 1-B rated extinguisher and a Class C fire with "B" rating of ten times a 1-B extinguisher.

EXTINGUISHING AGENT CHARACTERISTICS

There are a variety of common extinguishing agents. Each agent has specific characteristics, advantages and limitations, which are detailed in the following discussion and chart.

AGENT CHARACTERISTICS

Water: May contain **wetting agent** or antifreeze. High heat absorption. Suitable for Class A fires. Cools fuel below ignition temperature. Can also smother or reduce oxygen to some extent. The most effective agent for extinguishing deep-seated fires. **Water should not be used on Class C fires as it is a conductor of electricity.**

Carbon Dioxide: Inert gas that produces cold, white cloud on discharge. Can cause frostbite. Suitable for Class B and C fires. Oxygen displacement smothers fire.

Halon 1211: Liquefied compressed gas. Suitable for Class A, B and C fires. Interferes with chemical chain reaction. Has some smothering effect.

AFFF: Water and detergent that forms foamy solution when expelled through an aspiration nozzle and mixed with air. Suitable for Class A and B fires. Creates vapour seal to smother flames. Good wetting and penetrating properties on certain Class A fires.

Ordinator Base (Standard) Dry Chemical: Sodium bicarbonate, potassium bicarbonate, potassium chloride

or **ammonium phosphate.** Discharges as a bluish or white cloud. Agent is chemically processed to make it moisture resistant and free flowing. Suitable for Class B and C fires. Interrupts chemical chain reaction.

Multi-Purpose Dry Chemical: Monoammonium phosphate. Discharges as a yellowish cloud. Sticks to hot surfaces. Suitable for incipient Class A fire, and Class B and C fires. Interrupts chemical chain reaction.

EXTINGUISHERS

Dry Powder: Generally sodium chloride (Met-L-X) with additives to render free flowing. Forms solid mass when applied to burning metal. Agent must be matched to type of metal. Suitable for Class D fires (Met-L-X: sodium, potassium, magnesium, sodium/potassium alloys; Lith-X: lithium, magnesium, zirconium, titanium, sodium, sodium/potassium alloys). Smothers fire.

AGENT	ADVANTAGES	LIMITATIONS
Water	— not toxic — cools fire — absorbs more heat per volume than any other agent — can smother by steam formation (replaces oxygen) — can be pressurized — can be mixed with antifreeze for special application — good in below freezing temperatures if antifreeze is used — good range and penetration	— generally safe only for Class A fires — good in below freezing temperatures only if antifreeze is used — electrically conductive
Carbon Dioxide	— no **residue** — non-freezing	— limited range — affected by wind and draft — can be hazardous if used in a confined or unventilated space because CO_2 replaces O_2 — cold shock to electrical equipment
Halon 1211	— — no residue — non-freezing — twice as effective as CO_2 on a weight of agent basis — has about twice the range of CO_2 — no cold shock to electrical equipment as compared to CO_2	— limited range — affected by draft and wind (less than CO_2) — use in confined or unventilated space may be hazardous as the gases (vapours) formed by thermal decomposition are toxic
AFFF	— can make water float on fuels that are lighter than water — acts as a coolant and penetrant on Class A fires — smothers Class B fires — excellent wetting and penetrating properties due to low surface tension — vapour seal on fuels lighter than water	— leaves powder residue — will freeze — unsuitable for fires involving ethers, alcohols, esters, acetone if not alcohol based — limited use on Class A fires
Ordinary Base (Standard) Dry Chemical	— non-freezing — can be used in conjunction with water stream or fog — can be used in winds or drafts	— leaves residue — dry chemicals used on wet energized electrical equipment may aggrevate electrical leakage problems — can be corrosive — limited range — limited cooling effect
Multi-Purpose Dry Chemical	— used for **incipient** fires (Class A), plus Class B and C fires — non-freezing	— leaves residue — little cooling effect (Class A fires) — limited range
Dry Powder	— specific agents used for fires in specific metals	— incorrect application to shavings or metal dust can spread fire — not widely available

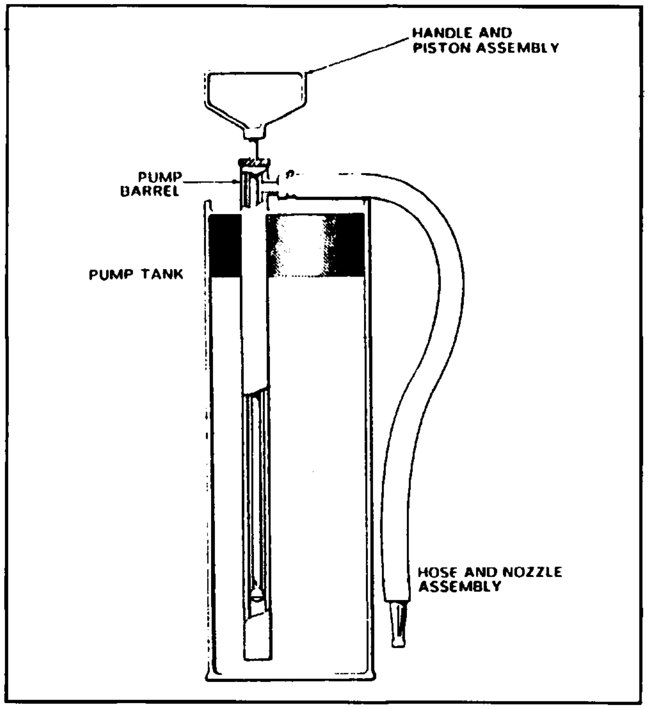


Plate 6-2. Pump tank type extinguisher.
Courtesy: Fire Academy — J.I. of B.C.

FIRE EXTINGUISHER TYPES

There are four types of extinguishers, each of which expels its extinguishing agent by a different means. The four types are: **hand operated pump, stored pressure, gas cartridge** and **self-expellent.**

1. **Hand Operated Pump Type:** For water type agents only. Metal **cylinder** with **carrying handle** attached to cylinder and built-in hand operated vertical double action pump that discharges water on continuous up and down strokes (Plate 6-2).
2. **Stored Pressure Type:** The **expellent** and agent are stored in a single cylindrical container. Top works include: gauge, carrying handle, **discharge lever,** and may or may not include a **hose.** This type can house most agents including: water, AFFF, Halon 1211 and dry chemical (including multi-purpose).

   When the operator releases the shut-off device, the expellent gas in the cylinder forces the agent out through the siphon tube (Plate 6-3).
3. **Gas Cartridge Type:** The expellent is contained in a separate pressure cartridge. This cartridge is normally attached to the outside of the cylinder, but can be enclosed in the cylinder with the agent. On external cartridge types, the carrying handle is on the opposite side from the cartridge, discharge lever and hose. Primarily dry powder and dry chemical types.

   When the pressure from the separate expellent gas cartridge is released into the agent cylinder through the gas tube, the gas pressure forces the agent out through the exit hose in the bottom of the cylinder (Plate 6-4).

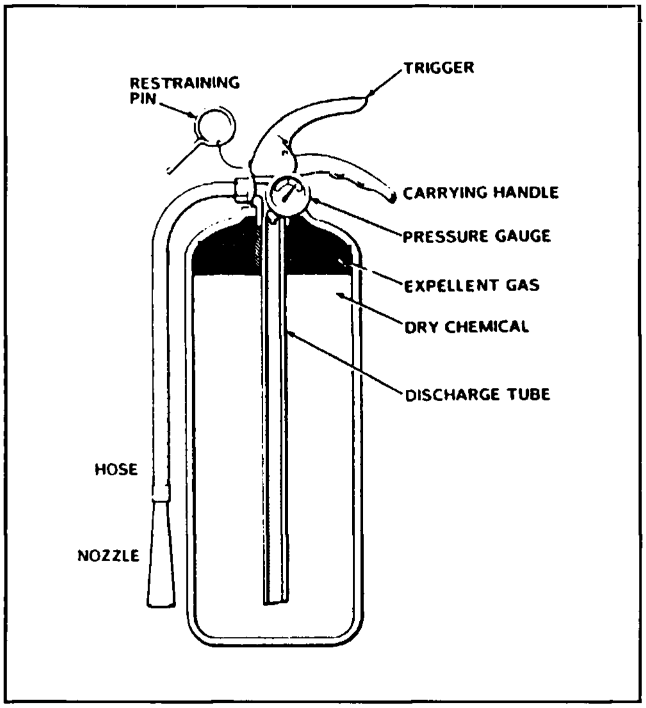


Plate 6-3. Stored pressure type extinguisher.
Courtesy: Fire Academy — J.I. of B.C.

4. **Self-expellent Type:** These agents have sufficient vapour pressure in normal temperatures to **expel** themselves when activated (Plate 6-5).

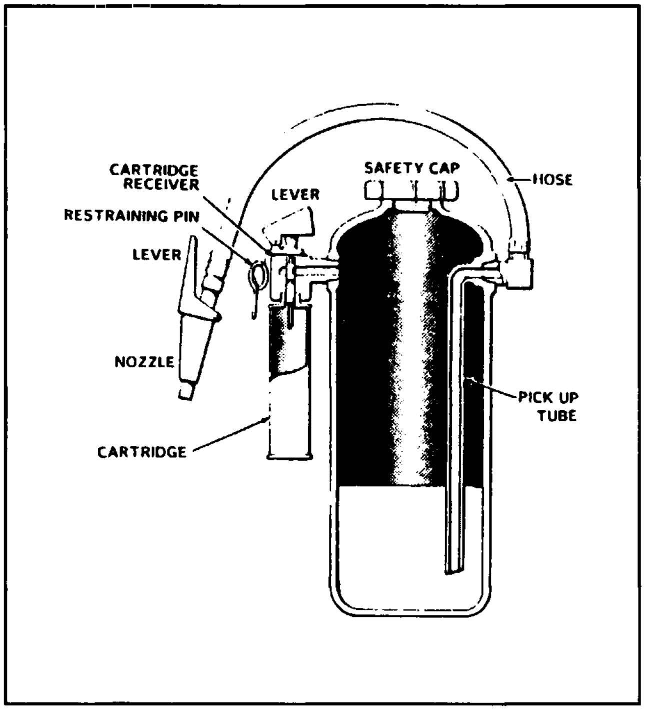


Plate 6-4. Gas cartridge type extinguisher.
Courtesy: Fire Academy — J.I. of B.C.

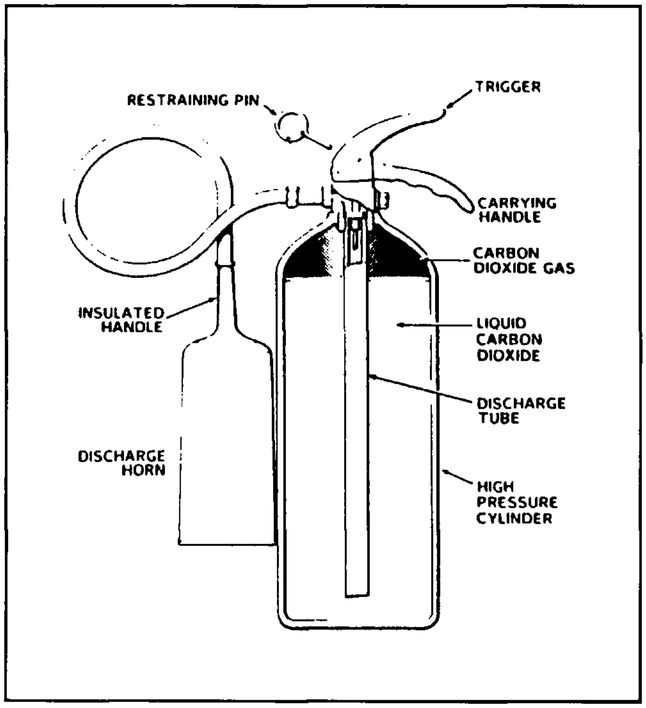


Plate 6-5. Self-expellent type extinguisher.
Courtesy: Fire Academy — J.I. of B.C.

INSPECTION

Visual checking of portable extinguishers is important in ensuring that an extinguisher will be fully operational in emergency situations.

When checking portable extinguishers for operational readiness, look for the following items that might require correction or follow-up (Plate 6-6).

- Position and legibility of faceplate
- Broken or missing seals, tamper indicators or lockpins
- Gauge to determine if fully charged
- Obvious physical damage to the cylinder such as corrosion and leakage
- Nozzles, hoses and couplings for cracks, deterioration, plugging
- Horns for cracks, dirt or grease accumulation
- Date of last recharge or inspection and **hydrostatic test**
- Pump cans for foreign objects inside and to ensure that they are full of water

Portable extinguishers should be hydrostatically tested as stated on each portable extinguisher's faceplate. Hydrostatic testing is a procedure, carried out by an authorized agency, that involves pressurizing extinguisher shells, cylinders or cartridges to pressures well above the **service pressure.** The purpose of this is to ensure that these components will not fail during the interval between routine maintenance checks.

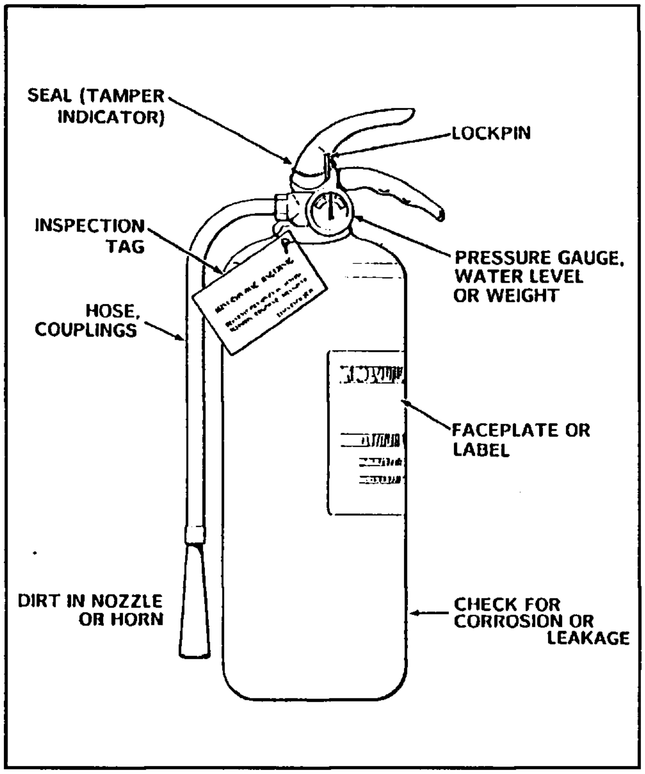


Plate 6-6. Areas to check.
Courtesy: Fire Academy — J.I. of B.C.

RESPIRATORY PROTECTIVE EQUIPMENT

TRAINING OBJECTIVES

Ventilation is not a serious problem around surface mining operations, nevertheless, every year workers are killed or injured because of dangerous amounts of gases or vapours, or not enough oxygen, in the the places where they work. Clearly, rescue teams going to the aid of the injured in these situations must avoid becoming victims themselves, and do so by wearing protective respiratory equipment. The objectives of this chapter are to familiarize rescue trainees with the use of this equipment.

Students will be required to:

- Identify the hazardous respiratory environments encountered in rescue work.
- Demonstrate the use of all types of protective breathing apparatus in a dense smoke environment.
- Identify the physical requirements of the wearer and the limitations and safety features of all types of breathing apparatus.
- Demonstrate the ability to put on breathing apparatus while wearing protective clothing.
- Demonstrate that protective breathing apparatus is in a safe condition for immediate use.
- Demonstrate the procedure for cleaning and sanitizing breathing apparatus after use.

INTRODUCTION

Oxygen deficiency or accumulations of dangerous gases can only occur in confined spaces, including buildings, manholes, tunnels, vaults, chemical tanks, oil tanks, storage bins, silos and sumps and, of course, in underground mine workings. Hazards that may be found in such places include:

- Toxic gases or vapours – gases that poison.
- Flammable gases or vapours – gases or vapours that ignite easily.
- Asphyxiant gases – gases that cause suffocation.
- Lack of oxygen.

Many people who expose themselves to a dangerous atmosphere are not aware that the danger exists or of the need to protect themselves. Where a dangerous atmosphere exists the hazards are best taken care of by proper and adequate ventilation (the exception to this rule is when a fire is involved). If a rescue team cannot ventilate an area and lives or property are at risk, proper respiratory equipment must be worn and all rescue teams should be trained in the use of self-contained breathing apparatus.

To control gases on a property, supervisors and rescue teams should be made aware of any special gas-producing chemicals used on their property and should be able to test an area to see if it contains a dangerous atmosphere. There are various methods and devices in use for detecting the presence and quantity of toxic, noxious and explosive gases (*see* Chapter 5). The presence of carbon monoxide and deficiency of oxygen are the greatest hazards in rescue or recovery work, but the chance of encountering other gases makes it necessary to train in the use of at least two of the following detectors:

- The multi-gas detector.
- Oxygen detector.
- Methane detector.

Special attention should be given to protective breathing equipment. The lungs and respiratory tract are probably more vulnerable to injury than any other part of the body, and the gases encountered in association with fires are usually dangerous in one way or another. It should be a fundamental rule in rescuing that no one be permitted to enter a building that is full of smoke and gas unless equipped with self-contained breathing apparatus. Failure to use this equipment may incapacitate rescuers and could lead to the failure of rescue attempts.

Warning: Breathing apparatus should not be worn when conditions such as a growth of beard, sideburns, a skull cap that projects under the facepiece, or temple pieces on glasses prevent a good face seal.

Presently, surface and underground mine rescue teams use both open-circuit and closed-circuit breathing apparatus. With open-circuit apparatus, the user's exhaled breath is discharged to the atmosphere. With the closed-circuit, it is recirculated through the breathing apparatus.

RESPIRATORY HAZARDS ENCOUNTERED IN FIGHTING FIRES

The four most common dangerous atmospheres found at fires are:

- Oxygen deficiency.
- Elevated temperatures.
- Smoke.
- Toxic gases.

OXYGEN DEFICIENCY

The combustion process consumes oxygen while producing toxic gases that either physically displace oxygen or dilute its concentration. When oxygen concentrations are below 18 per cent the human body responds by increasing the respiratory rate. Symptoms of oxygen deficiency are discussed in Chapter 3 (*see* Table 3-8).

ELEVATED TEMPERATURES

Exposure to heated air can damage the respiratory tract, and if the air is moist, the damage can be much worse. Excessive heat, temperatures exceeding 50 to 54°C (120 to

130°F), taken quickly into the lungs may cause a serious decrease in blood pressure and failure of the circulatory system. Inhaling heated gases may cause edema (fluid collection) in the lungs, which can cause death by asphyxiation. The tissue damage from inhaling hot air is not immediately reversible by introducing fresh, cool air.

SMOKE

Most of the smoke at a fire is a suspension of small particles of carbon and tar in air, but there is also some ordinary dust floating in a combination of heated gases. The particles provide nuclei for the condensation of some of the gaseous products of combustion, especially aldehydes and organic acids. Some of the suspended particles in smoke are merely irritating but others may be lethal. The size of the particles will determine how deeply they will be inhaled into the unprotected lungs.

TOXIC GASES

The effects of toxic gases are many and varied, and have been fully discussed in Chapter 3.

NON-SELF-CONTAINED (STANDARD DEMAND) BREATHING APPARATUS

NON-SELF-CONTAINED RESPIRATORS

Paint spray respirators provide respiratory protection for workers exposed to paint vapours and oversprays. Hazards covered include: lead-based paints; mists of paints, lacquers and enamels; organic vapours at concentrations up to 1000 ppm; and dusts and mists having a TLV not less than 0.05 milligram per cubic metre or 2 million particles per cubic foot. Different types of respirators are illustrated in Plate 7-1.

FILTER-TYPE SELF-RESCUERS

The filter-type self-rescuer is a small gas respirator designed to protect the wearer against carbon monoxide gas which is usually present in the air following a mine fire or explosion. It is small and easily carried on the underground miner's belt or on the machine the worker is operating. It can therefore be readily available in the case of emergency. Filter-type self-rescuers are also commonly stored in caches at strategic locations in mines. There are two models, the Dräger Model 810 (Plate 7-2) and the MSA Model W65 (Plate 7-3). Both are sealed at the factory and these seals should not be broken unless the self-rescuer is to be used. Once the seal is broken the chemicals in the apparatus deteriorate and the apparatus may become useless. The Model 810 is sealed in a vacuum while the model W65 is sealed under pressure in the inert gas nitrogen.

Miners should always examine their self-rescuers for dents or other external damage before using them. If the seal is broken or the container damaged, do not use it.

Although there are slight variations in design, both the Model W65 and the 810 operate on the same principle. When the wearer inhales through the mouthpiece, air is drawn in through the bottom of the self-rescuer and passes through the coarse-dust filter bag which encloses the lower part of the apparatus. Coarse dust is removed by this bag. The air then passes through a fine-dust filter in the bottom of the canister and through a drying agent which removes excess moisture which could reduce the effectiveness of the equipment.

After passing through the drying agent, the air flows through a chemical with the trade-name Hopcalite, which changes the deadly carbon monoxide gas to relatively harmless carbon dioxide. The air containing the harmless amounts of carbon dioxide is then breathed by the wearer, after its temperature is reduced by a heat exchanger.

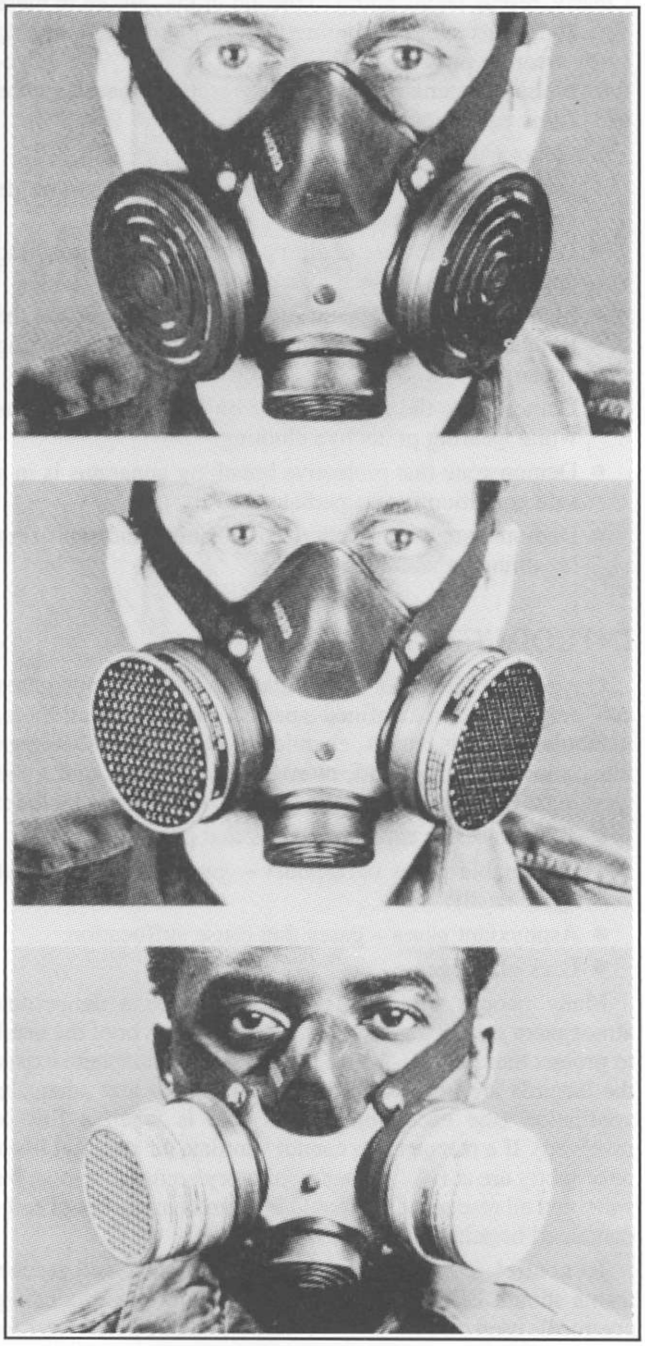


Plate 7-1. Examples of non-self-contained respirators.

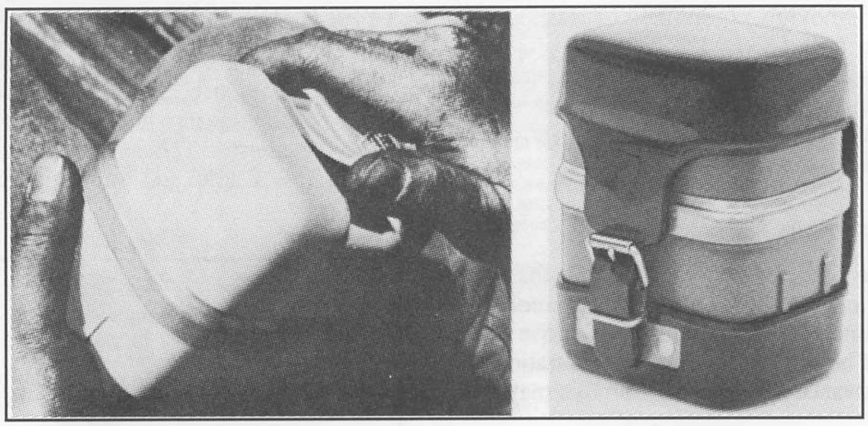


Plate 7-2. Dräger Model 810 self-rescuer.

Plate 7-3. MSA Model W65 self-rescuer.

When exhaled, the air again passes through the heat exchanger and out through a check valve to the outside air. The check valve allows air to pass outwards through it, but will not allow air to come in from the outside. All inhaled air must pass through the canister and is treated before it reaches the wearer's lungs (*see* Figure 7-1).

PROTECTION PROVIDED BY THE FILTER-TYPE SELF-RESCUER

The filter-type self-rescuer will protect the wearer against a carbon monoxide concentration of 1 per cent (10 000 ppm) for up to 1 hour, providing there is enough oxygen present to support life.

Protection is provided against higher concentrations of carbon monoxide for shorter periods of time, however, the heat buildup in the apparatus is quite rapid under these conditions. It is important to remember that a heat buildup in the air can be expected when using a self-rescuer in an atmosphere containing carbon monoxide. The hotter the air the more carbon monoxide is present, and the more important it is to continue using the apparatus. In spite of heat buildup the self-rescuer must be kept in the mouth until fresh air is reached. Death from carbon monoxide poisoning can be swift and is more permanent than the discomfort caused by breathing hot air.

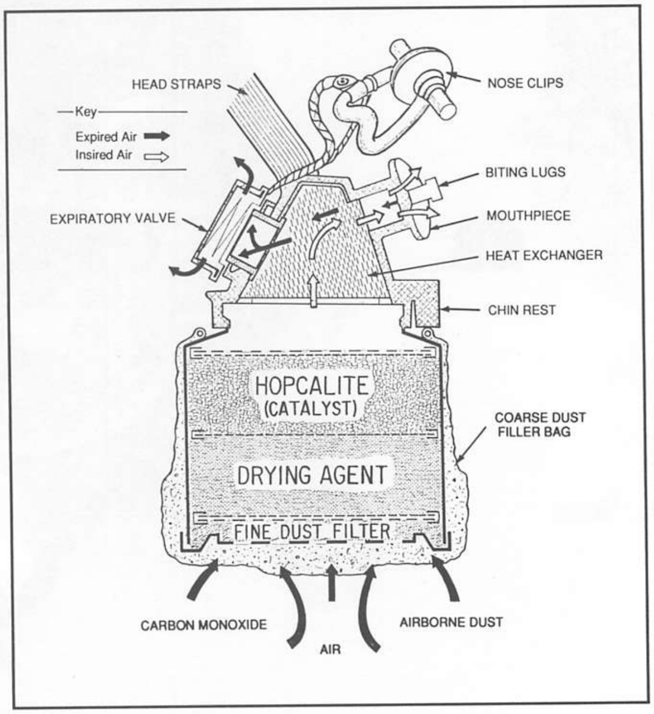


Figure 7-1. Cutaway diagram of Dräger filter-type self-rescuer.

When mounted on moving equipment or carried by miners, the self-rescuer has a service life of 5 years provided the seal is not broken. When placed in properly constructed caches the shelf life is indefinite. A properly constructed cache should be moisture proof as moisture will seriously affect the life of a self-rescuer.

WHEN THE SELF-RESCUER IS USED

The self-rescuer should be used immediately at the first indication of a fire or explosion, even though no smoke is visible. Waiting until smoke is apparent may well prove fatal because the area could be filled by a lethal concentration of carbon monoxide in advance of the smoke. Smoke may not appear at all.

OPERATION OF THE SELF-RESCUER

The first step in using a self-rescuer is to break the seal by raising the lever on top of the case. The cover is then removed and the apparatus taken out of the container. The mouthpiece is inserted in the mouth with the grip held between the teeth and the flange placed firmly between the teeth and lips to form a good seal. The nosepiece is then placed firmly over the nose so that the wearer is forced to breathe through the mouth. The head strap is placed over the head to support the weight of the self-rescuer. There must be sufficient oxygen in the air to sustain life (16 per cent by volume) for the self-rescuer to be effective.

TYPE-N CANISTERS AND MASKS

The Type-N mask (Plate 7-4) is a gas mask consisting of a full facepiece covering the eyes, nose and mouth, and a flexible, nonkinking breathing hose attached to an air-purifying canister. The canister is carried in a chest harness having a neck strap and waist strap to hold it tightly to the body.

Plate 7-4. Type-N canister and mask.

The facepiece is designed to give a comfortable gas-tight fit to a wide variety of facial sizes and shapes. However, one facepiece size will not fit all faces. A face-fitting program should be used to determine those persons who cannot be fitted.

The facepiece, hose and canister assembly must include check valves to allow air flow in one direction only. An inhalation valve is located at the top of the canister and an exhalation valve is a part of the facepiece. The incoming air to the facepiece is directed over the lens to reduce moisture condensation and where this is a significant problem, a nose cup can be installed to direct exhaled air to the exhalation valve without it touching the lens.

The Type-N canister is an air-purifying device that contains several chemicals for removing different gases, including carbon monoxide. It also contains a highly efficient filter for removing toxic particulates including smokes, dusts, mists and fumes. A window indicator is provided to give the wearer a visual indication when the canister is no longer able to convert carbon monoxide to carbon dioxide. A positive-closing external check valve is attached to the outlet of the canister and connects to the breathing hose.

The granular chemicals are placed in layers within the canister and a compression spring at the top of the canister keeps them in place, assuring that the incoming air contacts all the chemicals and all toxic contaminants are removed. The top of the canister also contains layers of filter material which are placed so that any dust from the chemicals cannot enter the facepiece when the mask is worn. Canisters have corrugated bodies or internal baffles to increase their efficiency. When a granular chemical is placed against a smooth surface, such as the side wall of the canister body, it does not pack as tightly to the smooth surface. This then becomes the path of least resistance for the air flowing through the canister. Corrugations or baffles cause the air to travel a longer path and come in contact with as much of the chemicals as possible. This prolongs the life of the canisters and prevents channelling.

Because the chemicals are affected by moisture, a top and bottom seal close the canister inlet and outlet and should always be kept in place while the canister is stored. Type-N canisters should be stored in a clean, dry location, away from widely varying temperatures and high humidity. The shelf-life is indefinite provided there is no change in the colour of the window indicator on the canister.

The function of the canister is to remove all toxic contaminants from the air drawn into it. This is accomplished as the air flows through the several layers of materials as summarized below:

(1) A high-efficiency filter removes particulate contaminants by mechanical filtration. The openings in the filter medium are small enough to remove particles or smoke that are submicron in size.

(2) Acid gases such as chlorine, sulphur dioxide, hydrogen sulphide and phosgene are absorbed chemically on materials that are caustic.

(3) Ammonia and other alkali gases are absorbed on chemicals that have an acid reaction.

(4) Organic vapours, or materials that generally contain carbon and hydrogen plus many other elements, are absorbed on the surface of activated carbon. Organic vapours include gasoline, paint solvents, chloroform and many others.

(5) The catalyst Hopcalite oxidizes the carbon monoxide to harmless carbon dioxide. It is placed above all the other canister chemicals which act as dryers to help keep moisture away from the Hopcalite as excess moisture will destroy it. When fighting fires with water, fog, foam, etc., and the canister is openly exposed, the Hopcalite could be destroyed in a few minutes.

(6) A layer of calcium chloride is placed at the top of the chemical bed to remove any moisture which may enter from the top of the canister. This is a protection for the Hopcalite when the canister is stored attached to the complete mask assembly.

The indicator window in the Type-N canister contains panels of two shades of a light blue colour. The darker shade section changes colour with a change in the moisture content of the Hopcalite directly behind it. The light section is a reference colour. When the canister picks up moisture during use or storage, the darker section will gradually become lighter in colour until it matches or becomes lighter than the reference section. When this change takes place the canister is no longer capable of oxidizing the carbon monoxide to carbon dioxide. The indicator window is designed to show the condition of the Hopcalite layer only and does not in any way relate to the other chemicals or the canister's ability to remove other gases.

Because the canister contains a variety of chemicals it provides protection against a variety of gases and vapours, as well as toxic particulates. The label on the canister describes its protection capabilities. The maximum concentrations in which the canister can be used are 2 per cent acid gases, 2 per cent organic vapours, 2 per cent carbon monoxide and 3 per cent ammonia. These limits were established by the United States Bureau of Mines a good many years ago and may be revised. The Type-N canister is painted red for identification. Other types of canisters providing protection against single gases, single classes of gas, or combinations of gases and vapours, are identified by other colours. With the exception of the mine rescue escape respirator, only the Type-N canister can give protection against carbon monoxide.

The most important thing to remember when using a Type-N canister is that it should never be used where the oxygen content of the contaminated air is not sufficient to sustain life (16 per cent by volume).

Type-N masks have sometimes been used for firefighting in atmospheres containing a high concentration of toxic gases and vapours and in areas having a low oxygen content, but they are no longer recommended for use in firefighting. A label stating "not to be used for firefighting" is attached to each canister. However where there is adequate oxygen, and some knowledge of the contaminant in the atmosphere, this type of mask can give very good protection.

When the Type-N mask is used to enter a toxic atmosphere (after it has been put on according to the instructions provided with each mask) the wearer should proceed cautiously and, if any odour or irritation is noted, should leave the area. The mask should be rechecked, tested for tightness, and the area again entered cautiously. Continued odour or irritation is an indication of a serious problem and the mask and canister should be completely checked. The wearer may also have facial characteristics that preclude the wearing of a mask.

Type-N canisters are designed and laboratory tested to meet performance requirements using test gases that are representative of the classes of gas the canister will protect against. The high concentration tests are made using 2 per cent of the gas by volume, in an air flow of 64 litres (2.26 cubic feet) per minute, low concentration tests in an air flow of 32 litres (1.13 cubic feet) per minute. Canisters and complete mask assemblies also must meet pressure-drop or resistance-to-breathing requirements. Tests are made at an air flow of 85 litres (3 cubic feet) per minute. The flow rates used are based on the requirements of people doing moderate to heavy work. A complete mask will have a resistance to inhalation of approximately 1 kilopascal (4 inches water gauge) and 0.15 kilopascal (0.6 inch water gauge) on exhalation at 85 litres per minute.

When the canister is used in an atmosphere containing several toxic gases and vapours, they are removed by the chemical layers as the air moves up through the canister. At the same time the gases are removed, water vapour is also taken from the air. Clean dry air that may contain only carbon monoxide then passes through the Hopcalite layer. This layer requires clean dry air to preserve its potency as long as possible. As the canister is used and approaches the end of its life, it will begin to pass low concentrations of the toxic gases. These can be detected by smell or irritation. The change in odour takes place gradually and will give the wearer adequate time to return to fresh air and replace the canister with a new one. Because carbon monoxide has no smell, the window indicator should be watched carefully; as long as the indicator section of the window shows a darker colour than the reference section, the canister will give protection against carbon monoxide.

It is extremely difficult to estimate the service life of a canister as it is affected by variable exposore conditions, including the concentration of contaminants in the air, the breathing rate of the wearer, temperature and humidity. However, for guidance purposes, tests have been made by the United States Bureau of Mines and the following minimum service requirements stipulated. At an average breathing rate of 25 litres per minute, in concentrations of 2 per cent for most gases and vapours, or 3 per cent for ammonia, the canister can predictably and reliably give protection against acid gases for 15 minutes; against organic vapours for 25 minutes; against ammonia for 15 minutes; and against carbon monoxide for 30 minutes. These times will be correspondingly higher at lower concentrations. Against carbon monoxide the canister life may range between 1.5 and 2 hours, depending upon the amount of moisture in the atmosphere. This time, however, should not be considered definite. The window indicator should be relied upon to tell when the canister will no longer protect against carbon monoxide. The canister also only gives protection where the total concentration of toxic gases does not exceed 2 per cent by volume. Where the combined concentration of toxic gases may possibly exceed this level, other types of breathing equipment should be used.

During use it is possible that the canister may become warm, or even hot. This is an indication that it is being exposed to relatively high concentrations of gases and vapours. Each of the reactions involved in their removal produces heat. This is most particularly true for the carbon monoxide reaction. When the incoming air entering the facepiece becomes intolerable, the wearer should retreat to a less contaminated area. It is also possible, under conditions of very high humidity, that an increase in breathing resistance will be noted. If this occurs the canister should be replaced even though an odour or irritation has not been observed.

Gas-mask canisters used for energency purposes should be replaced after each use. Specific indications for canister replacement or return to fresh air are:

- If the window indicator of the Type-N canister shows the specified colour changes.
- If any leakage is detected by smell, taste or eye, nose or throat irritation.
- If high breathing resistance develops.

The Type-N mask gives good protection when it is used wisely and its limitations are recognized. Rules to follow when using the mask are:

(1) Put on the mask carefully, following the manufacturer's instructions.

(2) Test for tightness and comfortable fitting of the facepiece. If leakage is noted take off the mask and repeat the procedure.

(3) Enter the contaminated area cautiously. If an odour or irritation is noted, return to fresh air and determine the cause.

(4) When odour or irritation is noted after the mask has been used, return to fresh air and replace the canister.

(5) If the canister and incoming air become hot, retreat from the contaminated area. The canister is being exposed to very high concentrations of toxic gases or vapours.

(6) Observe the indicator window frequently when exposed to carbon monoxide.

(7) Never use a Type-N mask where the oxygen content of the atmosphere is less than 16 per cent.

(8) Do not use the Type-N mask for firefighting or where the total toxic gas, vapour or particulate concentration exceeds 2 per cent by volume.

(9) Use suitable instruments to determine the concentration of oxygen and air contaminants.

SELF-CONTAINED OPEN-CIRCUIT POSITIVE-PRESSURE BREATHING APPARATUS

In the positive-pressure unit the diaphragm in the regulator is held open to create a slight pressure in the low-pressure hose and facepiece. This pressure is held in the facepiece by a spring-loaded exhalation valve so the pressure inside the facepiece is slightly higher than atmospheric pressure, preventing the entry of smoke particles and toxic gases. The insignificant amount of extra air expended is a small price for the added safety to the user. If the seal of the facepiece against the face is not good, however, there is still the possibility that toxic substances will be drawn into the facepiece if the user is breathing heavily; the seal of the positive-pressure facepiece is as important as it is for the demand facepiece.

Training is essential for rescuers to use the positive-pressure units efficiently. Some positive-pressure units can be converted to demand units by flicking a switch, but an unswitchable unit requires the user to be sure the cylinder valve or mainline valve is turned off until the facepiece is put on unless there is another shut-off valve. Rescuers may prefer to keep the mainline valve closed when the unit is not in use. When the cylinder valve is turned on, air will flow only as far as the regulator, but will be ready when needed. There may be confusion if the rescuer uses both demand and unswitchable positive-pressure units. With demand units, always keep the mainline valve open; with unswitchable positive-pressure units keep the mainline valve closed until ready to put on the facepiece before entering the hazardous area. Refer to manufacturer's instructions and department policy for specific units.

The four major components of an open-circuit positive-pressure breathing apparatus are:

- **Backpack assembly** – It is designed to hold the air cylinder on the rescuer's back.
- **Air cylinder** – It is designed to store a quantity of breathable air under pressure (Figure 7-2).
- **Regulator** – It is designed to reduce the high cylinder pressure to a specified flow and pressure required for inhalation.
- **Facepiece** – It is designed to deliver low-pressure air from the regulator into the mouth and nose of the rescuer. It may also provide some protection from facial burns and contact of smoke and fire gases with the eyes.

Regardless of the make of the breathing apparatus, each unit will contain the above four components. Again rescuers must be familiar with the particular make of breathing apparatus used by their team.

Three models of regulator are on the market today:

- **Automatic transfer (Scott 4.5 and 2.2)** – This system has no manual controls. Instead, the pressure-reducer system has a backup system that is automatically activated if the primary reducer fails. If the backup system is activated an alarm sounds; the rescuer must leave the contaminated area immediately. If the regulator fails to close, open the purge valve and close down the cylinder valve enough to regulate the flow, and leave the hazardous atmosphere immediately. Tag the equipment for repair and remove it from service immediately.
- **Manual bypass (MSA 401 and Survivair)** – During normal operation, the mainline valve is fully open while the bypass valve is fully closed. In an emergency, the bypass valve will provide an adjustable flow of air directly from the tank and into the facepiece, bypassing the regulator. The operation involves opening the bypass valve slightly to permit an adequate supply of air and closing the mainline valve completely. After inhalation close the bypass valve until another breath is required. While switching the bypass valve on and off, immediately retreat to fresh air.

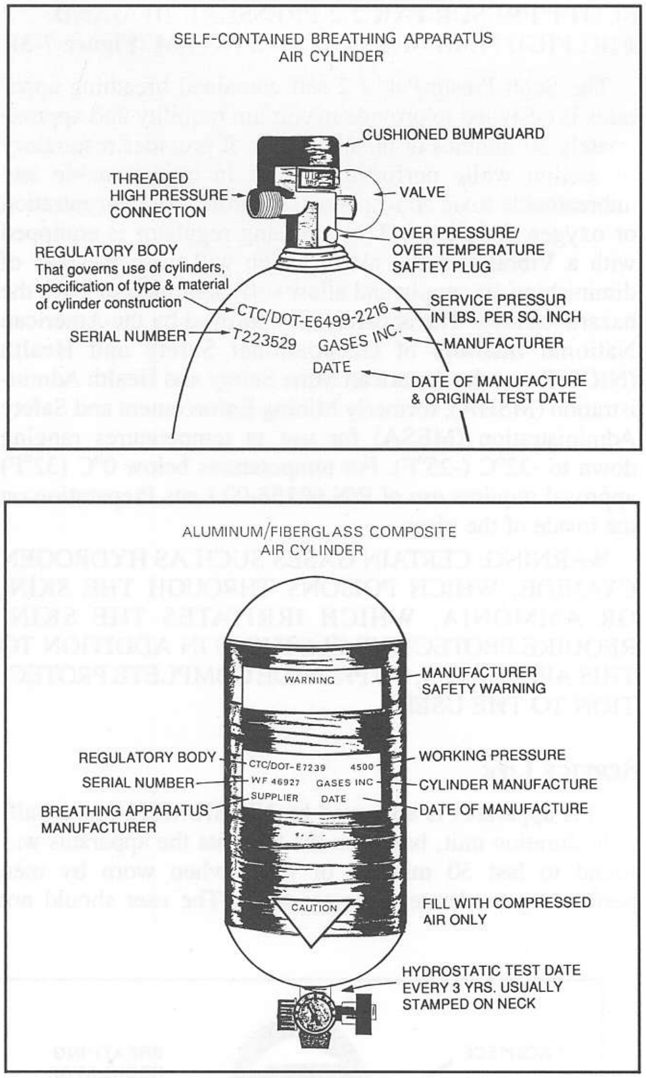


Figure 7-2. Air cylinder for self-contained open-circuit breathing apparatus.

This bypass procedure will use air at a slightly higher rate than in the mainline mode but will provide enough air for emergency escape. Most breathing apparatus that is equipped with the two-valve system, that is, mainline and bypass, will have one knob with rough edges and the other with round or smooth edges so they can be identified by touch. It must be second nature to every rescuer who wears breathing apparatus to be able to breathe using the bypass system in the event of regulator failure.

SCOTT PRESUR-PAK 2.2 PRESSURE-DEMAND FIREFIGHTERS BREATHING SYSTEM (Figure 7-3)

The Scott Presur-Pak 2.2 self-contained breathing apparatus is designed to provide maximum mobility and approximately 30 minutes of breathable air. It provides respiratory protection while performing work in objectionable and unbreathable toxic atmospheres, regardless of concentration or oxygen deficiency. The breathing regulator is equipped with a Vibralert audio alarm which will warn the user of diminishing air supply and allow sufficient time to leave the hazardous area. The apparatus is approved by the American National Institute of Occupational Safety and Health (NIOSH) and the American Mine Safety and Health Administration (MSHA), formerly Mining Enforcement and Safety Administration (MESA) for use in temperatures ranging down to -32°C (-25°F). For temperatures below 0°C (32°F) approval requires use of P/N 60158-00 Lens Preparation on the inside of the visor.

WARNING: CERTAIN GASES SUCH AS HYDROGEN CYANIDE, WHICH POISONS THROUGH THE SKIN, OR AMMONIA, WHICH IRRITATES THE SKIN, REQUIRE PROTECTIVE CLOTHING IN ADDITION TO THIS APPARATUS, TO PROVIDE COMPLETE PROTECTION TO THE USER.

SERVICE LIFE

This apparatus is approved by NIOSH/MSHA as a half-hour duration unit, based on the fact that the apparatus was found to last 30 minutes or more when worn by men performing moderate to heavy work. The user should not expect to obtain exactly 30 minutes service life on each use. The work being done may be more or less strenuous than that used in the tests. Where work is more strenuous the duration will be shorter, possibly as little as 15 minutes.

The duration of the apparatus will depend on such factors as:

- The level of physical activity of the user.
- The physical condition of the user.
- The degree to which the user's breathing is affected by excitement, fear or other emotions.
- The degree of training or experience which the user has had with this or similar equipment.
- Whether or not the cylinder is fully charged at the start of the work period.
- The possible presence of carbon dioxide concentrations in the compressed air greater than 0.04 per cent normally found in atmospheric air.
- The atmospheric pressure: if used in a pressurized tunnel or caisson at 2 atmospheres the duration will be one-half as long as when used at 1 atmosphere, and at 3 atmospheres will be one-third as long.
- The conditon of the apparatus.

PREPARATION FOR USE AND NORMAL OPERATION

The following procedure should be followed when using the apparatus:

(1) Open the carrying case lid.

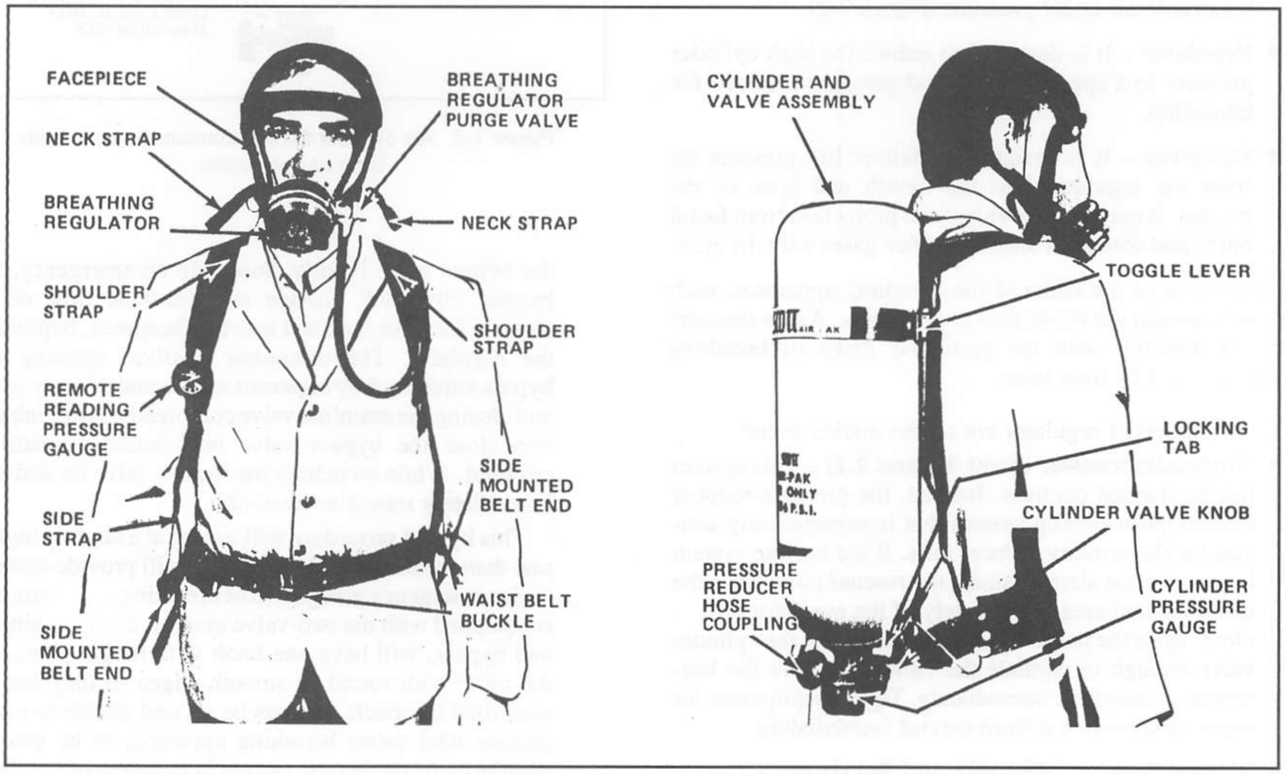


Figure 7-3. Components of Scott Presur-Pak 2.2 firefighter's breathing apparatus.

(2) Check the cylinder pressure gauge for FULL indication. If the indicated cylinder pressure is below FULL, recharge the cylinder to 15 000 kilopascals (150 atmospheres) or replace it with a fully charged cylinder.

WARNING: CYLINDERS WHICH SHOW EVIDENCE OF EXPOSURE TO HIGH TEMPERATURES OR FLAME (SCORCHED PAINT, MISSING OR CHARRED DECALS, GAUGE LENS MELTED, BUMPER DISTORTED) MUST BE REMOVED FROM SERVICE AND RETESTED PRIOR TO RECHARGING.

(3) Check that the breathing-regulator purge valve is closed (knob turned fully clockwise and pointer on the knob upward).

CAUTION: DO NOT USE TOOLS TO OPEN OR CLOSE THE PURGE VALVE. CLOSE OR OPEN FINGER-TIGHT ONLY. ROTATION OF THE PURGE-VALVE KNOB IS LIMITED TO A HALF TURN.

(4) Stand to the right (same end as the top of the cylinder) of the opened case, lean forward and spread out the shoulder straps. Grasp the back frame with both hands, the left hand on the pressure reducer and the right on the wire frame, and put on the apparatus. Different techniques for putting on self-contained breathing equipment are described and illustrated in detail later in this chapter.

(5) Take a deep breath and hold it while putting on the facepiece.

(6) Turn the cylinder-valve knob counterclockwise one and one-half turns. Listen for the Vibralert alarm to sound and then stop.

WARNING: IF THE ALARM FAILS TO SOUND OR DOES NOT SHUT OFF, DO NOT USE THE APPARATUS. REMOVE IT FROM SERVICE AND TAG IT FOR REPAIR.

(7) Check the face seal by listening for flow through the regulator while holding your breath, then breathe normally.

(8) Push in and rotate the cylinder valve clockwise to close the valve. Inhale on the facepiece and breathe on the residual air pressure. The Vibralert alarm will sound as the pressure drops below 3500 kilopascals (500 psi).

WARNING: IF THE ALARM DOES NOT SOUND, REMOVE THE EQUIPMENT FROM SERVICE AND TAG IT FOR REPAIR.

(9) While using the equipment check the remote-reading pressure gauge on the shoulder strap for a reading of the remaining supply. Allow sufficient time for leaving the contaminated area. The Vibralert alarm sounds when only 20 to 25 per cent of the air remains. Leave the area at once. If more than one Vibralert is sounding, users can identify their own alarms by changing the rhythm of their breathing. The tone of the alarm is modulated by inhalation.

(10) After use, and when in a safe area, push in and rotate the cylinder knob clockwise to close the valve. Remove the facepiece and cylinder together.

EMERGENCY OPERATION

WARNING: THESE PROCEDURES ARE FOR EMERGENCY USE ONLY; CONSEQUENTLY THE DURATION OF THE AIR SUPPLY AND THE AUDIBILITY OF THE VIBRALERT ALARM MAY BE REDUCED. THE EMERGENCY MODE SHOULD ONLY BE USED TO ESCAPE FROM A CONTAMINATED AREA.

(1) The system has no manual bypass controls. Instead the pressure-reducer assembly includes a backup pressure-reducer system that is automatically actuated if the primary reducer fails closed. When the backup system is actuated the Vibralert alarm sounds to warn the user.

(2) Should the breathing regulator fail closed, open the purge valve (red knob) to provide an acceptable flow of air.

(3) Should the system fail open (free flow), open the purge valve (red knob pointer down) and close the cylinder valve by pushing in and rotating it to regulate the air flow to satisfy the requirements of the user.

(4) Remove and tag the apparatus for repair.

CYLINDER REPLACEMENT PROCEDURE

(1) Push in and rotate the cylinder-valve knob clockwise to close the valve.

(2) Remove the facepiece to bleed down the residual pressure.

(3) Uncouple the pressure-reducer hose-coupling from the cylinder valve by rotating counterclockwise.

(4) Release the toggle level by pulling upward on its pull tab.

(5) Grasp the cylinder below the band, push the locking tab below the valve, lift the cylinder free from the bottom hook and remove it.

(6) Replace it with a fully charged cylinder and valve assembly. Slide the top of the cylinder upward under the band. Engage the cylinder hanger in the hook at the bottom of the backpack frame.

(7) Push the toggle lever to secure.

NOTE: Do not force the toggle lever. Adjust the band for a snug fit by sliding the band assembly on the angled side rails.

(8) Align and tighten the hose-coupling to the cylinder valve.

(9) The apparatus is ready for reuse.

CAUTION: DO NOT LEAVE THE CYLINDER VALVE OPEN WHEN THE APPARATUS IS NOT IN USE.

STAND-BY INSPECTION, CLEANING AND STORAGE PROCEDURE

Clean the apparatus after use as follows:

(1) Inspect the equipment for worn or aging rubber parts or damaged components.

(2) Remove the breathing regulator from the facepiece.

(3) If in good condition, carefully wash the facepiece assembly with warm soap or detergent solution and thoroughly rinse in clean water.

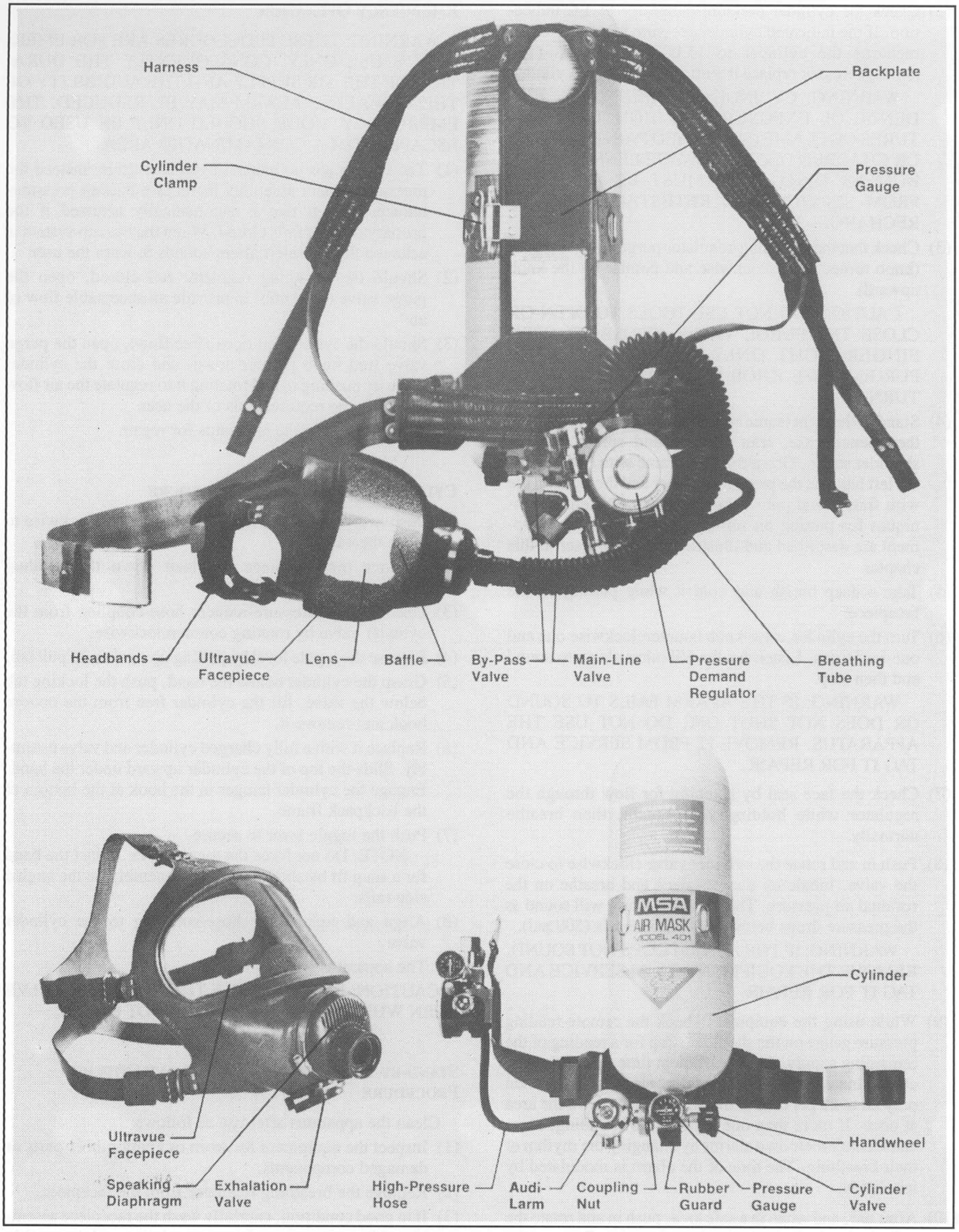


Figure 7-4. Components of Model 401 pressure-demand air mask.

(4) Disinfect the facepiece by sponging it with a 70 per cent solution of ethyl, methyl or isopropyl alcohol, a quaternary ammonium solution or a hypochlorite solution.

(5) Rinse and allow to completely air dry.

(6) Connect the breathing regulator to the facepiece, quarter-turn the coupling and rotate it until it latches in place.

(7) Damp-sponge dirt accumulations from the rest of the apparatus.

(8) Replace the apparatus in the carrying case, making sure all components are thoroughly dry.

MODEL 401 PRESSURE-DEMAND AIR MASK

The Model 401 Pressure-demand Air Mask is a pressure-demand self-contained breathing apparatus that provides respiratory protection under conditions of oxygen deficiency or in concentrations of toxic gases where it is necessary to avoid potential inward leakage that could result from the negative pressure that is developed in a demand apparatus. It is an open-circuit system that releases exhaled air to the surrounding atmosphere without reuse.

The Model 401 is approved by the National Institute for Occupational Safety and Health (NIOSH) and Mine Safety and Health Administration (MSHA), under Subpart H,30CFR, Part 11. It has Approval TC-13F-30 for 30-minute service. It meets the requirements of the United States National Fire Protection Association (NFPA) Standard 19B-1971 (Respiratory Protective Equipment for Firefighters); it also meets guidelines for self-contained breathing apparatus contained in the American National Standards Institute (ANSI) Standard Z88.2-1969 (Practices for Respiratory Protection) and ANSI Z88.5-1973 (Practices for Respiratory Protection and for the Fire Service).

MSA steel cylinders meet the requirements of the United States Department of Transportation Specification 3AA. The MSA Composite Cylinder has received the United States Department of Transportation Exemption 7277 for shipment in interstate commerce.

The Model 401 consists of an Ultravue facepiece assembly equipped with a spring-loaded exhalation valve and breathing tube, a pressure-demand regulator that supplies air to the facepiece under positive pressure, a high-pressure hose that links the regulator to the Audi-Larm audible low-pressure warning device, a high-pressure cylinder to store the compressed air and a harness assembly for carrying the apparatus on the wearer's body (Figure 7-4).

Recent Occupational Safety and Health Association (OSHA) standards specify the use of pressure-demand apparatus only for firefighting or emergency entry into unknown concentrations of toxic gases. The unit is approved for entry into and escape from irrespirable atmospheres. It can be used in extremely toxic atmospheres where even minute levels of inward leakage into the facepiece would be dangerous. It has a rated service life of 30 minutes. Service life rating is based on the results of tests conducted by the National Institute of Occupational Safety and Health (NIOSH).

OPERATION

Standard demand units adjust automatically to deliver the air supply necessary to satisfy breathing requirements with air pressure inside the facepiece the same as outside (so under some circumstances there is a possibility of inward leakage). With the pressure-demand air mask apparatus, air is delivered to the facepiece at a pressure of approximately 0.25 kilopascal (1 inch water gauge). This slight positive pressure is controlled by a spring on the regulator diaphragm. Flow stops during exhalation because the exhalation valve opens at approximately 0.4 kilopascal (1.5 inches water gauge) positive pressure. The pressure inside the facepiece therefore remains positive during both inhalation and exhalation. With this pressure-demand system the danger of inward leakage is minimized, yet breathing resistance is low. Because of these operating differences, pressure-demand regulators and facepieces must never be interchanged with demand regulators and facepieces.

ULTRAVUE FACEPIECE

The Ultravue facepiece is supplied with the Model 401 Pressure-demand Air Mask. It has a one-piece replaceable lens that is molded out of polycarbonate plastic, five adjustable head bands and a speaking diaphragm to project the sound of the user's voice through the mask. The plastic lens is treated with Abcite (trademark of E.I. duPont de Nemours & Co. Inc.) scratch-resistant coating. Rubber components are made out of a compound that is soft and resistant to facial oils. An internal baffle controls lens fogging by deflecting exhaled air away from the lens. The baffle also directs the sound of the user's voice into the speaking diaphragm. Exhaled air vents to the surrounding atmosphere through an exhalation valve.

Ultravue facepiece accessories include a spectacle kit for mounting prescription lenses inside the facepiece without disturbing the facepiece seal, a nosecup assembly to reduce the possibility of lens fogging [NIOSH requires the use of this accessory when the apparatus is used at temperatures below 0°C (32°F)], and a cover lens to provide additional facepiece-lens protection.

Two facepieces are available. Because facepiece fit is so important in a pressure-demand apparatus, MSA offers the larger Clearvue facepiece in addition to the standard Ultravue pressure-demand facepiece to provide a broader range of effective face-to-facepiece fits.

PRESSURE-DEMAND REGULATOR

The pressure-demand regulator supplied with all MSA Pressure-demand Air Masks can deliver high-volume air flow to meet breathing demands during periods of extreme exertion, while maintaining a positve pressure in the facepiece. The regulator reduces the high pressure of the cylinder air to a breathable pressure and automatically meters the flow of air to the facepiece during inhalation and exhalation, maintaining a slight pressure above ambient atmospheric pressure. The MSA regulator design incorporates both high-pressure and low-pressure relief devices which preclude the possibility of damage to the regulator's internal components

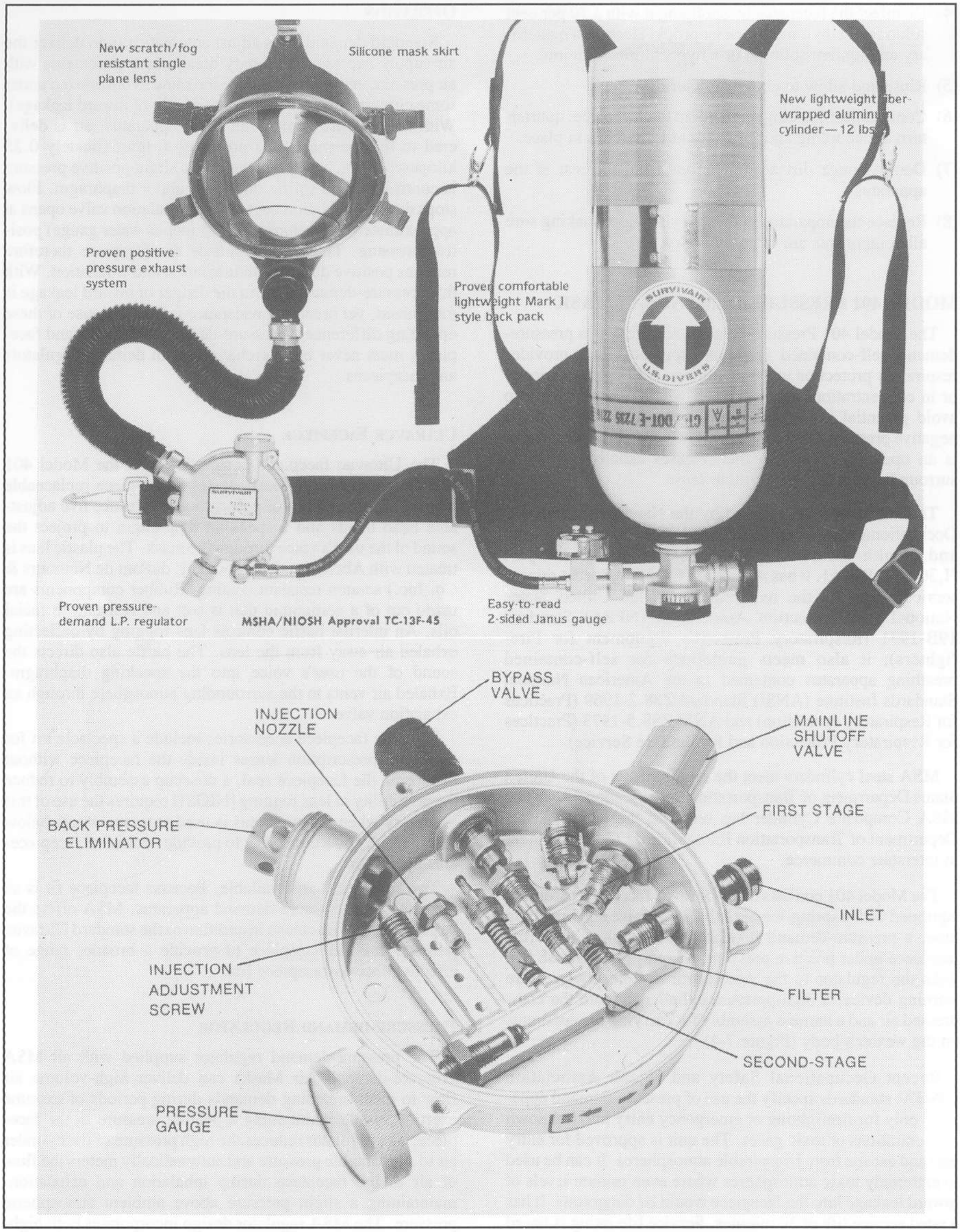


Figure 7-5. Components of Survivair 30-minute self-contained breathing apparatus, with cutaway view of the two-stage pressure-demand regulator.

or diaphragm cover in the event of a buildup of excessive pressure. The regulator is connected to the facepieee by the breathing tube.

Under normal operating conditions air flow through the regulator is controlled by a mainline valve that is equipped with a round, yellow knob. However, should the automatic regulator mechanism be damaged or fail to operate, a bypass valve with a six-sided red knob provides a controlled, direct and constant flow of air from the cylinder. The difference in shapes of the mainline and bypass knobs allows identification by touch in a smoke-filled or dark area. A pressure gauge on the regulator indicates remaining air pressure in the cylinder. High-pressure air is delivered to the regulator by a length of high-pressure hose.

AUDI-LARM WARNING DEVICE

The Audi-Larm supplied on the Model 401 gives an audible warning when the cylinder air pressure drops below a preset level. It alerts the user that the air supply is nearing exhaustion and warns the user to leave the toxic area. The assembly is installed between the high-pressure hose and the cylinder-valve outlet. It is joined to the cylinder valve by a hand-tightened coupling nut. The Audi-Larm is automatically made ready to operate when the cylinder valve is opened.

When the cylinder pressure reaches approximately 3800 kilopascals (550 psi) the piston in the warning device begins to strike a nickle-plated brass bell. The ringing contiuues until the cylinder pressure drops below approximately 1500 kilopascals (200 psi). The operating pressures are preset at the factory.

Total ringing time depends on cylinder capacity. When connected to a 1275-litre (45 cubic feet) capacity cylinder (as on the air mask) the bell will ring for approximately 6 minutes. When ringing, the Audi-Larm consumes less than 2 litres (0.07 cubic foot) of air per minute (a small fraction of the total remaining air supply).

CYLINDERS

The Model 401 can be furnished with one of two types of cylinders, a lightweight composite (aluminum-fibreglass) cylinder which weighs approximately 4.8 kilograms (10.5 pounds) or the standard steel cylinder weighing approximately 8 kilograms (18 to 20 pounds). Both cylinders have an air-storage capacity of 1275 litres (45 cubic feet) when charged to a pressure of 15 000 kilopascals (150 atmospheres) and both are refilled with the same equipment. The composite cylinder and the steel cylinder are interchangeable on pressure-demand air masks and demand air masks.

The steel cylinders are made of high-strength chromium-molybdenum steel. The air mask composite cylinder is a seamless aluminum-alloy tank wound over its entire surface with high-strength S-glass filaments impregnated with epoxy resin. All cylinders are hydrostatically tested to 5/3 of the rated pressure in accordance with the United States Department of Transportation requirements.

The composite cylinder has a cadmium-plated valve and the steel cylinder has a nickel-plated valve. All cylinders are equipped with a flush-mounted pressure gauge. A removable rubber guard protects the gauge if the cylinder is dropped. The cylinder-valve handwheel, mounted at a right angle to the valve stem for ease of operation and protection from damage, controls the flow of high-pressure air to the pressure-demand regulator.

HARNESS AND BACKPLATE

The Cushionaire harness of the Model 401 has a foam-padded 5-centimetre-wide (2-inch) nylon strap at each shoulder and a padded strap across the bottom of the backplate where contact is made with the wearer's back. The backplate is made of 32-millimetre ($^1/_8$-inch) anodized aluminum and is painted black. The cylinder clamp is an adjustable mechanism that compensates for small variations in outside cylinder dimensions. It consists of a cam-type latch that can engage any of six slots in the stainless steel spring clip. The cylinder is changed by opening the cam latch, slipping out the empty cylinder, slipping in the recharged cylinder and twisting the cam latch to the locking position.

CARRYING CASE

Pressure-demand self-contained breathing apparatus is supplied in a molded plastic case to facilitate carrying the equipment and to protect it in storage. The pressure-demand air mask case is approximately 70 by 45 by 30 centimetres (27 by 18 by 11 inches) and weighs approximately 5.4 kilograms (12 pounds) empty.

SERVICE LIFE

Approvals from NIOSH/MSHA for duration of use (30 minutes) for the Model 401 are based on tests conducted by NIOSH. The apparatus was tested with a breathing machine at a use rate of 40 litres (1.4 cubic feet) per minute and was able to supply air for the rated service life or longer. Work performed by an actual user may be more or less strenuous than the work level simulated in the test and this difference will affect service life. During extreme exertion, for example, service life may be reduced as much as 50 per cent. Service duration of each unit is influenced by the same factors as for the Scott Presur-Pak system (*see* page 82).

INSPECTION AND MAINTENANCE

The pressure-demand air mask should be inspected and maintained in accordance with OSHA regulations 1910.134(f) and ANSI Standards Z88.2 and Z88.5 (for the Fire Service) which recommend that self-contained breathing apparatus be inspected routinely before and after each use. Apparatus not used routinely, but kept ready for emergency use, should be inspected after each use and at least monthly.

Caution:

Repairs to breathing apparatus must never be attempted beyond the scope of the manufacturer's recommendations. They must be sent to the manufacturer, or an authorized MSA air mask service centre, for adjustment or repair.

Parts must not be interchanged between self-contained breathing devices from different manufacturers.

Cylinders must be filled to the required pressure before use, 15 000 kilopascals (150 atmospheres). Only respirable air, free of all organic substances and other contaminants, should be used to refill the cylinder. Refill air should be at least Grade D gaseous air as described in the United States Compressed Gas Association Commodity Specification for Air, G-7.1, ANSI Z86.1-1973.

Proper cleaning agents, such as MSA Cleaner-Sanitizer, must be used to sanitize the unit after each use so that rubber components do not deteriorate. NEVER use alcohol as a germicide because it may deteriorate the rubber. Do not apply heat to rubber parts to speed drying.

MSA pressure-demand regulators must not be interchanged with MSA demand regulators; MSA pressure-demand facepieces must not be interchanged with MSA demand facepieces.

Inspection After Each Use

ANSI requires that immediately after use, each device must be inspected for cylinder pressure, facepiece and breathing-tube wear and cracking, and damage to the exhalation valve, speaking diaphragm and other parts. Then the apparatus is cleaned, disinfected, checked again by sight and sound for normal operation, and stored in a ready position.

During this inspection, look for missing, cracked or broken parts in the facepiece, breathing-tube assembly, regulator and harness. Inspections of the exhalation valve must be limited to a visual check. Do not remove the exhalation valve assembly.

After each use, the regulator should be dried to help prevent corrosion and possible regulator freeze-up during cold weather. To do this, remove the diaphragm cap, spring and diaphragm. Use a paper towel or clean cloth to dry the low-pressure side of the regulator and the parts. Be careful not to bend the arms on the lever assembly. When the regulator is dry, place the short lever arm on top of the long lever arm. To install the diaphragm, place the side with the metal plate down, facing the lever assembly. Insert the spring in the centre hub of pressure-demand units and replace the diaphragm cap.

Following the inspection, the date and initials of the designated person should be recorded on the MSA inspection tag. A more detailed record of the operations performed can be noted on the MSA inspection and maintenance log. *See* page 00 for more details.

MSA 401 Pressure-demand Bench Test

(1) Remove from case.
(2) Check cylinder pressure, 15 000 kilopascals (150 atmospheres).
(3) Cover regulator outlet.
(4) Open cylinder valve fully.
(5) Open regulator valve (check pressure).
(6) Close cylinder valve (check for drop in regulator gauge high-pressure leaks).
(7) Uncover regulator outlet slowly [Audi-Larm should ring at 3450 to 3800 kPa (500-550 psi)].
(8) Close regulator valve.
(9) Check regulator-valve seat (open cylinder valve and watch regulator gauge; indicator should not move).
(10) Close cylinder valve.
(11) Check bypass-valve seat (apply soap bubble over outlet orifice).
(12) Check admission valve spring removed (open regulator valve and apply soap bubble over outlet orifice).
(13) Check bypass function (open and close bypass valve).
(14) Put on the apparatus.
(15) Check facepiece:
    (a) straps;
    (b) hoses;
    (c) lens;
    (d) gaskets;
    (e) apply fogproof.
(16) Put on the facepiece and check for seal.

SURVIVAIR 30-MINUTE UNIT

The pressure-demand feature of Survivair's 30-minute unit is designed to provide positive pressure to the user at times of immediate threat to life or health. It maintains a slight positive pressure to the mask.

The apparatus has six major component parts (Figure 7-5):

- Facepiece.
- Low-pressure hose assembly.
- Regulator.
- Audible alarm and high-pressure hose assembly.
- Cylinder and valve assembly.
- Back-Pack.

FACEPIECE

Survivair's facepiece is one of the leaders in the industry today. The full-vision design provides approximately 300 square centimetres (45 square inches) of vision area. This allows the user to see areas on each side of his face normally obscured by other facepieces on the market. The skirt of the mask is manufactured from silicone rubber, a synthetic material that is resistant to heat radiation, dry rotting, ozone deterioration, alcohol and most degreaser solvents. Silicone is also chemically inert and does not react with perspiration, whereas neoprene rubber masks may cause skin inflammations around the sealing surface. Silicone's pliability also allows the wearer to obtain maximum sealing integrity with a minimum of headstrap pressure. The facepiece is designed with a deflector plate on the inside, which deflects exhaled air out of the mask. The deflector plate also causes the incoming air to be diverted toward the inside lens surface which reduces fogging. The lens surface is coated with a material from Dow Corning which is chemically resistant to acetone, gasoline and most chemical degreasers. This coating also protects the lens surface from becoming scratched and making the mask difficult to see through.

LOW-PRESSURE HOSE ASSEMBLY

The low-pressure hose has a large diameter in order to reduce the effort of inhalation. The hose is made from a synthetic rubber material which will withstand temperatures to −57°C (−70°F) and remain flexible. It is constructed with a large number of corrugations giving good crush resistance yet enabling the hose to be stretched easily with a minimum of effort.

REGULATOR

Mainline Valve

The mainline valve is colour-coded silver and is the lowest knob on the regulator, making recognition easy in dark or smoky areas. It functions to open and close the regulator and contains the first stage of the two-stage design. The external knob also contains a twist-locking mechanism which prevents accidental closing and is designed to lock the mainline valve in the open-ready position.

Bypass Valve

The bypass valve is coloured red and functions as an emergency source of air. Caution must be used when activating the bypass valve because air is being metered directly from the cylinder and routed to the mask around the normal regulating mechanism (the bypass is designed to provide air in emergency situations only and not to be used instead of changing the unit to pressure demand).

Pressure Gauge

The pressure gauge provides the user with a constant reading of cylinder air pressure. The gauge reads pressure in increments of 100 psi (≈700 kPa) for precise readings.

Filter Assembly

The filter is manufactured from sintered bronze and is capable of filtering out particles of dust larger than 50 microns.

Adjusting Screw

The adjusting screw is designed as an external adjustment to make the regulator deliver more or less air to the user. Adjusting the screw downwards causes the regulator to deliver more air and adjusting the screw upwards causes the regulator to deliver less air upon inhalation. The adjusting screw allows the user to make the self-contained breathing apparatus fit his particular breathing requirements (the adjusting screw is preset at the factory, 2¾ turns).

AUDIBLE ALARM AND HIGH-PRESSURE HOSE

The alarm is made of aluminum for weight reduction. It is designed to begin ringing at a pressure of 3450 kilopascals (500 psi) and continue ringing until the unit runs out, which will take approximately 5 minutes. The thread connection is a 436 CGA thread. The high-pressure hose is manufactured neoprene with a nitril inner liner to provide strength.

CYLINDER AND VALVE ASSEMBLY

The cylinder is manufactured 3AA steel. The rated working pressure is 13 900 ± 70 kilopascals (2015 ± 10 psi) which, when tested by NIOSH for duration, gave a typical user about 30 minutes at a rate of 40 litres (1.4 cubic feet) per minute.

The cylinder valve has a janus-type gauge which allows the user to determine the air pressure from either side of the cylinder. A soft rubber bumper below the gauge helps cushion it from sudden shocks. The cylinder valve also incorporates a soft rubber handle, with a safety ratchet locking device, at right angles to the cylinder for ease of operation once the unit is put on.

BACK-PACK

The Back-Pack is modeled on an alpine hiker's pack. This design reduces fatigue to the wearer because the weight is distributed to the hips instead of on the shoulders or upper back. The Back-Pack has three adjustable nylon straps, one on each shoulder and one around the waist, making it easy to put on and adjust. The tubular frame also gives strength with lightness of weight.

PROCEDURE FOR USING THE SURVIVAIR MASK

(1) Check the cylinder pressure. Open the case and check the cylinder pressure gauge reading to ensure that the cylinder is full (15 000 kPa; 150 atmospheres).

(2) Check that the high-pressure hose is securely attached to the regulator and cylinder valve. Tighten firmly with the fingers.

(3) Lift the unit out of the carrying case by grasping the left shoulder strap with the left hand and the regulator with the right hand. Put on the unit; techniques for putting on the equipment quickly and easily are discussed in a later section of this chapter.

(4) Open and lock the mainline valve; close the bypass valve.

(5) Remove the dust cover from the regulator outlet.

(6) Place the regulator control knob in the demand position before opening the cylinder valve. Open the cylinder valve three full turns and check the pressure reading on the regulator pressure gauge.

(7) Put on the facepiece.

(8) Test the facepiece; cover the end of the breathing tube with one hand and inhale. If there are no leaks, the facepiece will collapse against the face. Continue holding a hand over the end of the breathing tube and exhale to check the exhalation valve. If leakage occurs, readjust the facepiece, retighten the straps and repeat the test. Place the exhalation kob into the press mode.

(9) Connect the breathing tube to the regulator and tighten the coupling firmly with the fingers.

(10) Place the pressure-demand lever on the regulator down to the pressure mode.

STORING AND CLEANING THE SURVIVAIR MASK

After each use the tank should be recharged to the full position (15 000 kPa; 150 atmospheres). The mask should be checked for any torn or broken headstraps and these replaced as needed. The mask should be cleaned with warm soapy water, rinsed with clean water and hung to dry at room temperature.

Yellow inspection cards should be attached to each unit; inspections should be made at least once per month and the cards initialed by the person making the checks.

RECHARGING CYLINDERS

Recharging of air cylinders is usually done from a bank of large air cylinders. In some cases, the large cylinders are connected to an air compressor designed specifically for air-breathing systems. This is called a "cascade system" (Figure 7-6). Steps for recharging cylinders include:

Step 1 – Inspect the cylinder for damage and hydrostatic test date.

Step 2 – Place the cylinder in the charging station, connect the charging hose.

Step 3 – Open the cylinder valve.

Step 4 – Slowly open the valve of the cascade cylinder with lower pressure.

Step 5 – When SCBA and cascade cylinder pressure are equal, close the cascade cylinder valve and open the valve on the cascade cylinder with next highest pressure.

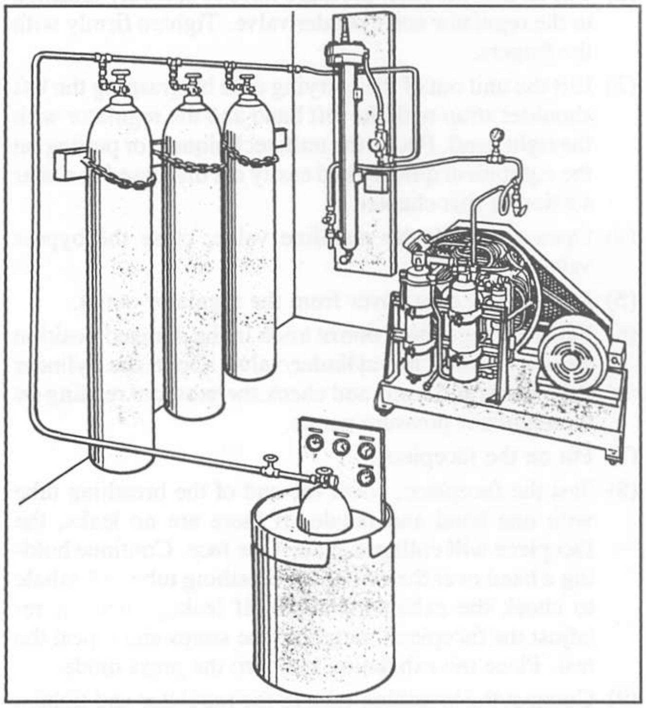


Figure 7-6. A cascade system used for recharging small air cylinders. The cascade of large bottles may or may not be connected to an air compressor and purification system.

valve on the cascade cylinder with next highest pressure.

Step 6 – Repeat Step 5 until the SCBA cylinder is charged.

HIGH-PRESSURE OXYGEN BOOSTER PUMPS

The pumps described below are multivalve piston-type pumps for compressing oxygen and transferring it from one cylinder to another at the desired pressure. Both hand-operated and power-driven pumps are available. **No oil or grease of any kind should be used in any type of high-pressure oxygen pump. Chemical reaction between the lubricant and the oxygen may result in a violent explosion.**

DRÄGER HIGH-PRESSURE OXYGEN PUMP U200 OR U300

This unit (Plates 7-5 to 7-7) is a two-cylinder pump capable of boosting the pressure in the cylinder to be charged to either 14 000 kilopascals (2000 psi) or 21 000 kilopascals (3000 psi) depending on the setting of the automatic control. **The 21 000 kilopascal setting may only be used when charging Dräger BG 174 or OXY-SR bottles.**

The level of lubricant in the reservoir of the pump must always be visible in the glass gauge tube on the end of the reservoir. The circulating lubricant must be observed in motion under the two plastic domes on the console during the pumping operation. The correct lubricant mixture is one part glycerine to four parts water. Complete operating and maintenance procedures are described in the manufacturer's pump manual.

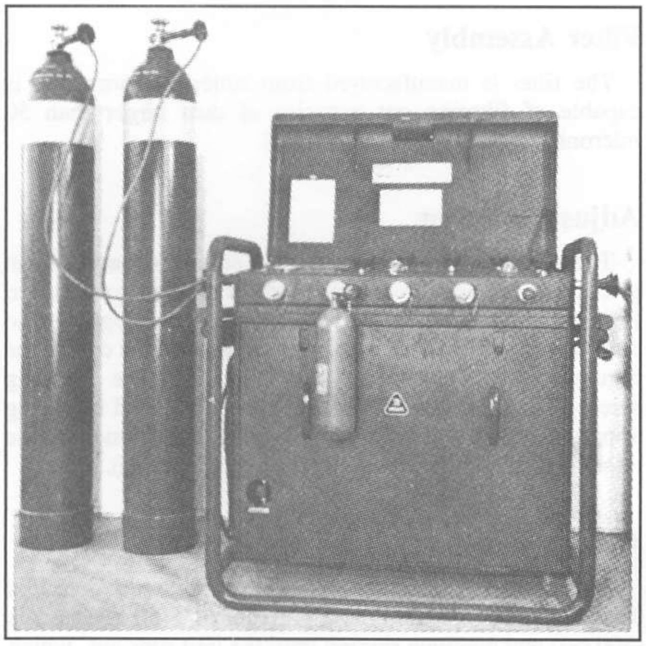


Plate 7-5. Dräger oxygen pump with bottle connected.

Plate 7-6. Dräger oxygen pump; control panel.

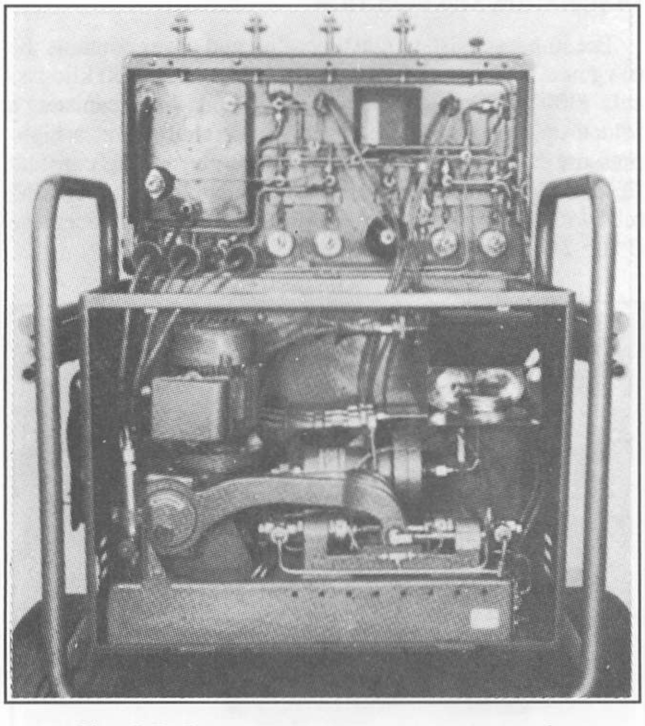


Plate 7-7. Dräger oxygen pump; covers removed.

Haskel High-pressure Oxygen Booster Pump

This unit (Plate 7-8) is a two-stage air-operated oxygen booster pump capable of boosting the pressure in the cylinder to be charged as high as 30 500 kilopascals (4450 psi) depending on the setting of the automatic control. It is a fully portable unit, but should only be operated by trained personnel following the manufacturer's operating and maintenance instructions.

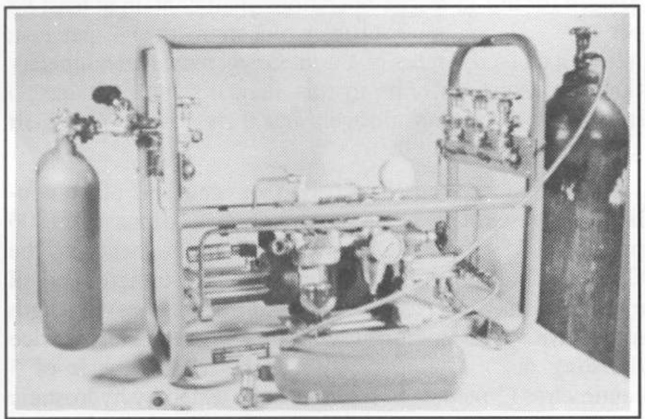


Plate 7-8. Haskel high-pressure oxygen booster pump.

CHARGING APPARATUS BOTTLES BY PRESSURE EQUALIZATION

Small apparatus bottles can be recharged by equalizing their pressure with that of large cylinders using a cascade system. A manifold has been designed to be connected to two or three large cylinders which should be chained upright or otherwise fastened to prevent them from falling over (Figure 7-6).

Arrange the cylinders so that the one with the lowest pressure is to the right as you face them and the one with the highest pressure is on the left. Connect the rigid inlet-coupling of the manifold to the middle cylinder and attach flexible hoses to the outer cylinders. A special coupling containing a filter is used to connect the manifold to the small bottle being filled. Take care to see that the oxygen flows in the direction of the arrow on the filter and follow the procedure below.

(1) Open the main valve on the small bottle.

(2) Open the valve on the right-hand cylinder and close it again as soon as all sound of oxygen flow has stopped.

(3) Repeat with the valve on the centre cylinder and, if necessary, repeat with the third.

(4) Close the bottle valve, the main adaptor valve and the valve on the large cylinder. Open the bleeder valve on the adaptor and disconnect the bottle.

All valves should be opened slowly to prevent excessive heat generation; watch the pressure gauges while opening the valves.

If only two large cylinders are available, remove the hose on the left side of the manifold, close off the opening with the cap attached to the manifold and then follow the same recharging procedure.

OXYGEN AND OXYGEN CYLINDERS

The purity of oxygen used in rescue apparatus is very important as impurities tend to accumulate in the circulatory system of breathing units. For this reason any equipment using compressed air supplied by oil-lubricated compressors should not be converted into oxygen without cleansing and purging. The United States Bureau of Mines specifies that oxygen for use in rescue operations shall contain at least 98 per cent oxygen, no hydrogen, not more than 2 per cent nitrogen and only traces of argon. Oxygen made by liquefaction processes conforms to this standard and contains no impurities other than nitrogen and traces of the rare inert gases.

All cylinders used to transport oxygen and other non-liquefied gases at pressures exceeding 2100 kilopascals (300 psi) at 21°C must comply with the requirements of the Canadian Transport Commission regarding strength, and all cylinders which exceed 30 centimetres (12 inches) in length must have valves equipped with an approved safety device (bursting disc). Cylinders with an outside diameter of 5 centimetres (2 inches) or more must be tested by hydrostatic pressure at least once every 5 years and the date of testing must be marked on the cylinder as required by the Canadian Transport Commission. Composite bottles are required to be tested more frequently.

The tests consist of determining the "elastic expansion" (total expansion minus permanent expansion) when the bottle is subjected to hydrostatic pressure. Bottles that are normally charged at 14 000 kilopascals are tested at 21 000 kilopascals and those capable of being charged at 21 000 kilopascals are tested at 44 000 kilopascals.

SELF-CONTAINED CLOSED-CIRCUIT BREATHING APPARATUS

Closed-circuit breathing apparatus, also known as rebreathers, recycle the user's exhaled breath after removing carbon dioxide and moisture and adding supplemental oxygen as needed. None of the oxygen used and none of the exhaled waste gas is released outside the facepiece. For all practical purposes all gases in the system stay in the system, travelling in a closed circuit. The oxygen comes from a cylinder of compressed oxygen and is supplied at a rate greater than that needed for breathing alone. The additional gas increases the pressure in the facepiece during inhalation and exhalation. The slight positive pressure is maintained mechanically in the breathing chamber by a device that exerts a force on the breathing diaphragm. Reuse of the exhaled air results in longer duration and lower unit weight. The carbon dioxide scrubber must be changed and the oxygen cylinder recharged or replaced after each use.

Several self-contained self-rescue units are manufactured in West Germany for use in mines. The Auer self-rescuer is a miniature chemical oxygen producing unit with a quick-start canister. It provides a 45-minute supply of oxygen. The oxygen is quite hot as the compactness of the unit does not allow for cooling. The more commonly used Dräger units are described in more detail below.

THE DRÄGER OXY-SR RESCUER

The Dräger OXY-SR rescuer is supplied in two models which are the same except for the oxygen release valve. The OXY-SR 45 has a push-button valve which can be operated once only. It supplies oxygen from a small storage tank pressurized to 30 000 kilopascals (300 atmospheres) for a 45-minute period at a flow rate of 1.2 litres (0.04 cubic foot) per minute (Table 7-1). The unit must be returned to the factory for replacement of the push-button valve.

TABLE 7-1
DURATION OF DRÄGER OXY-SR 45 SELF-CONTAINED BREATHING APPARATUS

Charging Pressure	Duration
300 atmospheres (30 000 kPa)	45 minutes
200 atmospheres (20 000 kPa)	30 minutes
135 atmospheres (13 000 kPa)	20 minutes

The OXY-SR 30 has a hand-operated valve control and can supply oxygen for 30 minutes at a rate of 1.5 litres (0.05 cubic foot) per minute. This unit can be recharged by means of an oxygen cascade system and high-pressure pump.

Both models are supplied with mouthpieces or facemasks. When mouthpieces are used, a pair of goggles should be packed inside the lid of the carrying case. A complete unit, with case, weighs approximately 2 kilograms (5 pounds).

DESCRIPTION AND FUNCTION

The impact-resistant plastic casing and cover contains the oxygen cylinder with a working pressure of 30 000 kilopascals (300 atmospheres), a refillable soda-lime canister, a folded-up breathing bag with pressure-relief valve, a high-pressure control valve with a 1.5 litre per minute constant flow and lung-demand regulator, and a corrugated breathing tube with mouthpiece and nose clip, or optional full facepiece (Plate 7-9).

Plate 7-9. Components of Dräger Model OXY-SR 30 self-contained oxygen breathing apparatus.

With the cover open, mouthpiece and nose clip fitted, and cylinder valve open, the required oxygen supply is maintained by the constant flow unit and the lung-demand regulator. The operation of the latter is essential as it fills the breathing bag in the first seconds of use.

The air passes through the breathing tube into the soda-lime canister where the carbon dioxide is absorbed. The respirable air flows on into the breathing bag where oxygen from the constant dosage unit is added. On inhalation the air flows through the double nonreturn valve and the breathing tube to the mouthpiece. The OXY-SR self-rescuer is thus self-contained breathing apparatus (Figure 7-7).

At low respiratory rates, excess gas is eliminated through the pressure-relief valve. When the apparatus is put into operation it functions automatically. After use the oxygen cylinder must be recharged and the soda-lime canister refilled.

OPERATING PROCEDURE

(1) Open the cover and put on the unit.
(2) Insert the mouthpiece and adjust the nose clip or, if the unit has a full facepiece, put on in the regular manner (Plate 7-10) and adjust the face straps.
(3) Open the cylinder valve and breathe.

OXY-SR 30 AND 45 STATION TEST

Leak Test at Negative Pressure

(1) Pump air from the breathing bag until the needle on the test apparatus lies between −8 and −10 centimetres water gauge (−0.8 to −1.0 kPa) (*see* Testing Instruments for Oxygen Breathing Apparatus, this chapter).
(2) Switch the test unit to LEAK TEST and briefly press the red button until the pointer rests at −7 centimetres water gauge (0.7 kPa). Watch the needle. The pressure should not change by more than 15 millimetres water gauge over a period of 60 seconds.

Leak Test at Positive Pressure

(1) A positive-pressure leak test can also be carried out. Proceed in the same way as above, after completely inflating the breathing bag. In this test, however, the pressure-relief valve must be covered with the protective cap to prevent it from opening.
(2) Remove the cap again after the test.

Testing Pressure-relief Valve

(1) Set the test unit to POSITIVE-PRESSURE PUMPING and completely inflate the breathing bag.
(2) With the breathing bag filled, watch the test unit and continue to pump slowly and evenly.
(3) The pressure-relief valve must open at a pressure of +2 to +6 centimetres water gauge (0.2 to 0.6 kPa).

Testing the Constant Dosage Unit

(1) Hold the pressure-relief valve in position with the index finger and middle finger (or use the cap). With the breathing bag rigidly inflated, switch the test unit to DOSAGE TEST.
(2) With a test cylinder charged at 300 atmospheres (30 000 kPa), the rate of flow in the OXY-SR 45 should be 1.1 to 1.4 litres per minute (1.15 to 1.45 litres per minute with the test cylinder charged at 150 to 200 atmospheres) and 1.4 to 1.7 litres per minute in the OXY-SR 30 (1.45 to 1.75 litres per minute with the test cylinder charged at 150 to 200 atmospheres).
(3) If the cap is used in this test, do not forget to remove it after completing the test.

Testing the Lung-controlled Valve

- Set the test unit to NEGATIVE-PRESSURE PUMPING and slowly operate the bellows. As soon as you hear the lung-demand regulator respond, read the pressure on the test unit. The regulator should operate at a pressure of −1 to −4 centimetres water gauge (0.1 to 0.4 kPa).

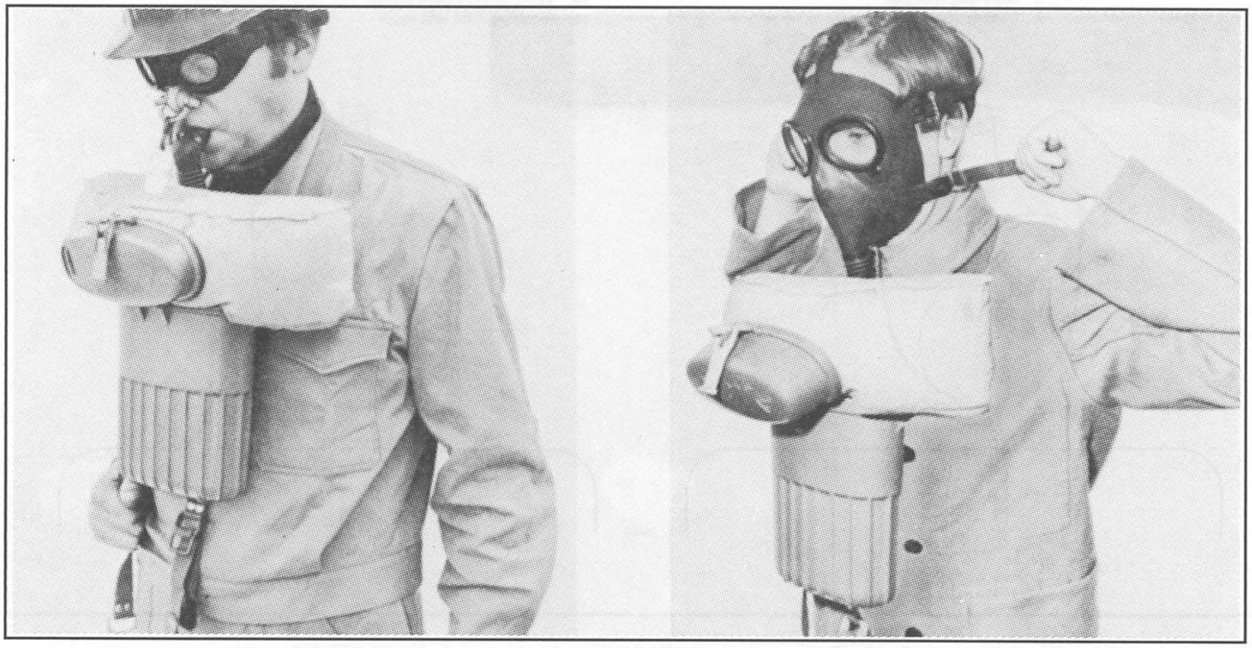
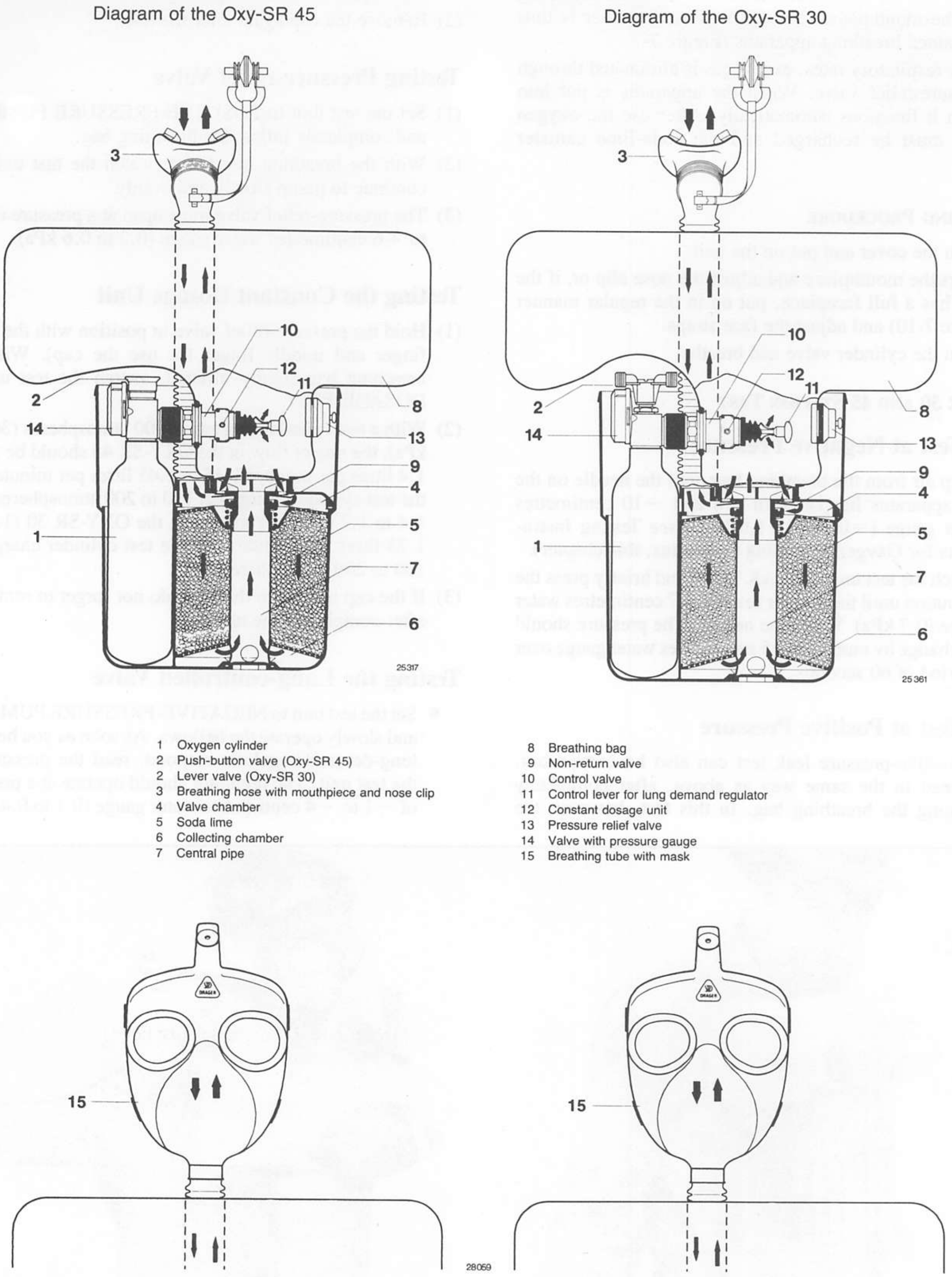


Plate 7-10. Wearing the Dräger Model OXY-SR 30 self-contained oxygen breathing apparatus.



1	Oxygen cylinder
2	Push-button valve (Oxy-SR 45)
2	Lever valve (Oxy-SR 30)
3	Breathing hose with mouthpiece and nose clip
4	Valve chamber
5	Soda lime
6	Collecting chamber
7	Central pipe
8	Breathing bag
9	Non-return valve
10	Control valve
11	Control lever for lung demand regulator
12	Constant dosage unit
13	Pressure relief valve
14	Valve with pressure gauge
15	Breathing tube with mask

Figure 7-7. Circuit diagram for the Dräger Model OXY-SR 30 self-contained closed-circuit breathing apparatus.

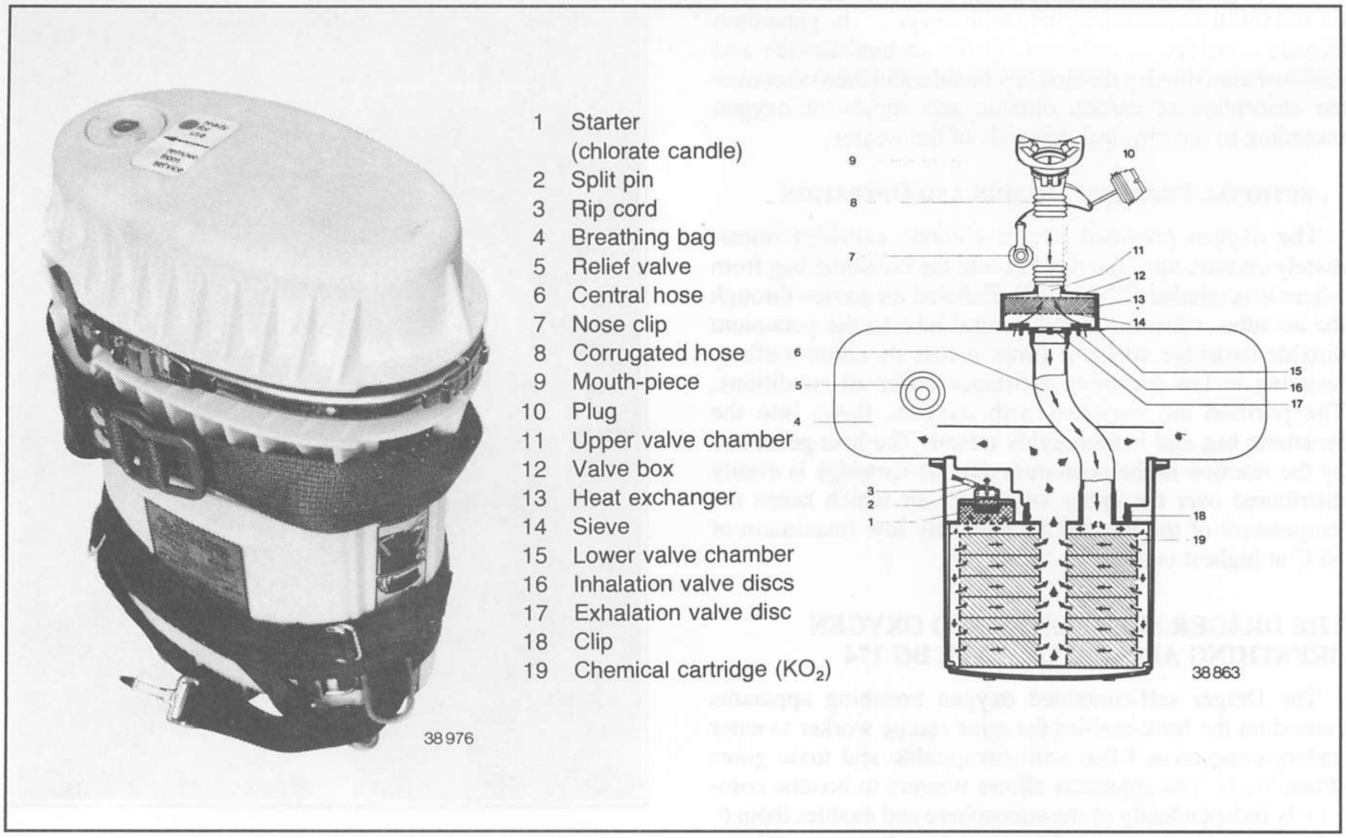


Plate 7-11. Dräger Model OXY-SR 60B self-contained breathing apparatus.

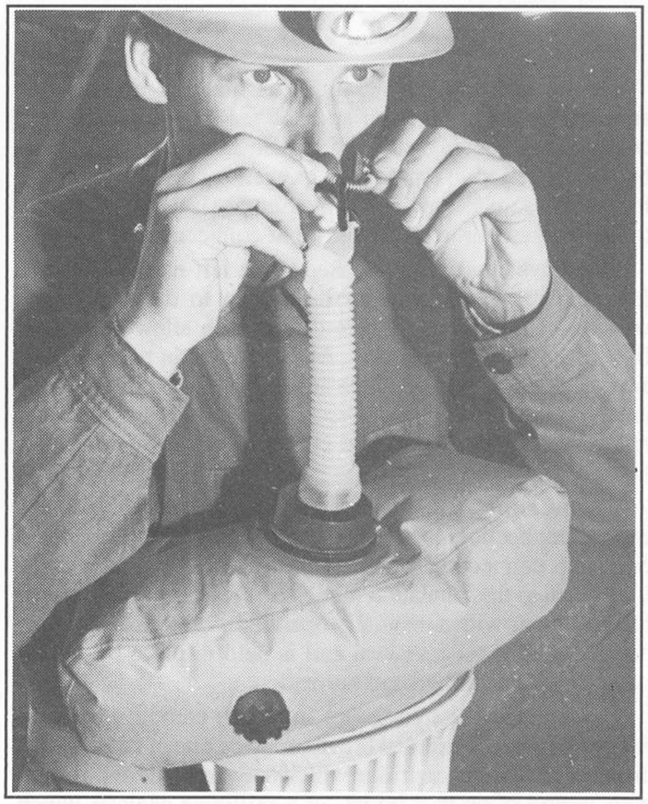


Plate 7-12. Wearing the Dräger Model OXY-SR 60B self-contained breathing apparatus.

Avoiding Oxygen Loss During Testing

Tests which require consumption of oxygen are best carried out with a second cylinder and not the one which will be used to equip the apparatus tested.

- When a test cylinder is used, it must be replaced by a fully charged cylinder after completing the tests, screwing the apparatus cylinder firmly to the control valve by hand.
- A test cylinder with lever valve (as in the OXY-SR 30) is required for testing the OXY-SR 45 with push-button sealing mechanism.
- The pressure gauge must be checked again after fitting the apparatus cylinder and when preparing the equipment for use. The needle must lie in the green area of the meter.

THE DRÄGER OXY-SR 60B OXYGEN BREATHING APPARATUS

The Dräger OXY-SR 60B is a closed-circuit unit which provides oxygen and absorbs the carbon dioxide in exhaled air in a potassium dioxide cartridge. A chlorate cartridge assures the supply of oxygen before the potassium dioxide cartridge is activated. The breathing system is contained in a compact, high-strength plastic housing complete with breathing bag, goggles and mouthpiece assembly (Plate 7-11). The housing is hermetically sealed and a humidity indicator in the lid shows that the unit is in working order. The chlorate cartridge is automatically activated by opening the lid and fills the entire air system with oxygen. The potassium dioxide cartridge is activated by the carbon dioxide and moisture contained in the first few breaths and then takes over the absorption of carbon dioxide and supply of oxygen according to the physical demands of the wearer.

FUNCTIONAL PRINCIPAL, DESIGN AND OPERATION

The oxygen provided by the chlorate cartridge immediately on start-up is fed directly into the breathing bag from where it is inhaled (Plate 7-12). Exhaled air passes through the air tube, valve block and central tube to the potassium dioxide cartridge where it flows across its entire surface, resulting in low breathing resistance under all conditions. The purified air, enriched with oxygen, flows into the breathing bag and is thoroughly mixed. The heat generated by the reaction in the potassium dioxide cartridge is evenly distributed over the entire volume of air which keeps the temperature of the inhaled air relatively low (maximum of 46°C at highest output).

THE DRÄGER SELF-CONTAINED OXYGEN BREATHING APPARATUS, TYPE BG 174

The Dräger self-contained oxygen breathing apparatus carried on the back enables the mine rescue worker to enter underground areas filled with irrespirable and toxic gases (Plate 7-13). The apparatus allows wearers to breathe completely independently of the atmosphere and enables them to effect rescue and recovery in extremely arduous conditions.

Plate 7-13. Dräger Model BG 174 self-contained breathing apparatus in use.

This closed-circuit apparatus is light in weight (12.7 kilograms; 28 pounds), but its construction is rugged and highly resistant to mechanical shock. The exhaled air is freed of its carbon dioxide content in a regenerative canister and passed into a breathing bag. The purified air is then withdrawn from the breathing bag during inhalation.

The oxygen consumed during respiration is replaced from a compressed oxygen supply through constant-flow metering at the rate of 1.5 litres (0.05 cubic foot) per minute and, if this is not sufficient to supply the wearer, additional oxygen is provided by a lung-demand valve.

When the apparatus is first turned on, the circuit is automatically flushed with approximately 6 litres (0.2 cubic foot) of oxygen. Apart from the occasional checking of a pressure gauge, the apparatus requires no further attention during its use. Its operating functions are entirely automatic.

DESCRIPTION OF MAIN PARTS

The apparatus consists of six main parts: oxygen bottle, oxygen control assembly, valve assembly, breathing tubes and facepiece, regenerative canister, and breathing bag (Plate 7-14).

The oxygen bottle is a high-grade alloy steel cylinder with an atmospheric volume of 2 litres. When charged to a pressure of 14 000 kilopascals (2000 psi) it contains approximately 270 litres (9.5 cubic feet) and at its maximum pressure of 21 000 kilopascals (3000 psi) it will contain approximately 400 litres (14 cubic feet) of oxygen. The bottle must by hydrostatically tested every 5 years to comply with Transport Canada regulations. The testing pressure is 30 000 kilopascals (4400 psi).

The oxygen control assembly is made of brass and is attached to the right-hand wall of the carrying frame. It contains the reducing valve, the preflushing unit, the manual bypass valve for an emergency oxygen supply and the valve for the pressure gauge line. This assembly is coupled directly to the oxygen bottle by a hand-tight connection.

The valve assembly, attached to the left-hand wall of the frame, controls the delivery of oxygen to the wearer and consists of a metering device designed to allow a constant flow of 1.5 litres per minute. Also included in the assembly are a demand valve to provide additional oxygen if required, inhalation and exhalation valves, a warning device, pressure-relief valve, check valve and connections for the breathing tubes.

The breathing tubes are made of corrugated rubber with a central connection to attach the facepiece, with individual couplings connecting to the valve assembly. A moisture trap is attached to the inhalation tube. **The facepiece** has a curved full-view lens with a manually operated wiper. The neoprene mask has an inner face-seal and is held in place by a five-strap, quick-adjusting head harness.

The regenerative canister, in which carbon dioxide is removed from the exhaled breath, may be one of two types: a disposable alkaline cartridge which may be used for a continuous period of up to 4 hours, or a refillable canister which may be used for a maximum period of 2 hours. The use of the alkaline cartridge provides drier air for breathing. The wearer

Plate 7-14. Components of Dräger Model BG 174 self-contained breathing apparatus.

is therefore under less physical stress than when using the refillable canister.

The breathing bag is made of three-ply rubberized fabric. It is so arranged within the carrying frame that it is protected on all sides, but is able to function without obstruction. It contains a coupling for the valve assembly connection and an elbow connection to the regenerative canister. The minimum capacity of the breathing bag is 6 litres.

AUXILIARY PARTS

The carrying frame and harness – The frame is made of corrosion-resistant light alloy. The flat side-walls, together with the curved plates of the regenerative canister support at the top, and the cylinder support at the bottom, constitute a torsion-resistant frame. The backplate acts as a protective cover for the breathing bag space. All fittings are attached to the strong side-walls. The regenerative canister support is so arranged that the canister itself is properly cooled and the transfer of heat to the back of the wearer by conduction and radiation is minimized. The rear of the frame has a resilient pad of rubberized fabric with a steel insert, ensuring a comfortable fit and proper separation of the apparatus from the body of the wearer. The harness is made of nylon-cotton fabric, is comfortable to wear and easily adjusted.

The cover protects the components of the apparatus when in use and is easily removable.

The gauge tube and gauge – The tube is a rubber-covered, high-pressure, flexible and closely wound spiral hose. The clear, easily read pressure gauge is fitted with a swivel connection to facilitate correct positioning.

CLOSED-CIRCUIT OPERATION

The exhaled air containing carbon dioxide flows from the mouth through the exhalation tube, to the exhalation valve and then to the regenerative canister where the carbon dioxide is absorbed. The absorption process is accompanied by the production of heat, increasing the temperature of the canister and the air flowing through it. The air, freed of carbon dioxide and respirable, then flows into the breathing bag.

During inhalation the air is drawn from the breathing bag and flows through the valve assembly via the inhalation valve, to the inhalation tube and to the facepiece connection. The air within the apparatus is thus continuously inhaled and exhaled in a closed circuit. Its direction of flow is controlled by valves.

Constant-flow Metering

In normal operation the oxygen consumed during respiration is replaced by constant-flow metering at the rate of 1.5 litres per minute. With the bottle valve open, high-pressure oxygen flows through the control assembly where pressure is reduced to 393 kilopascals (57 psi) at which it flows through the oxygen line, the metering device and into the valve assembly where it replenishes the closed-circuit air.

Relief Valve

If oxygen consumption is less than the supply through the constant-flow metering system, the breathing bag becomes overinflated during exhalation. The excess pressure in the breathing bag causes the control diaphragm in the valve assembly to move to the left against a spring. An orifice in the centre of the diaphragm is equipped with a sealing lip which is lifted off a sealing plate, enabling the excess air to flow through the diaphragm and escape to outside air through a nonreturn valve.

Automatic Demand Valve

Under conditions of extreme physical effort the oxygen requirement may exceed that supplied by constant-flow metering. In such circumstances the breathing bag fills to a progressively smaller degree with each breathing cycle until finally its contents no longer supply the wearer with oxygen. A negative pressure is then created which immediately moves the diaphragm of the valve assembly to the right. The sealing plate of the relief valve is then actuated so that a plunger pushes the lever of the demand valve to the right, opening the valve. Oxygen then flows through the oxygen line into the valve assembly and into the inhalation chamber until the wearer's requirements are again fully satisfied.

Warning Signal

The oxygen line is fitted with a bellows in the line to the valve assembly. The control bellows is hinged by a double-arm lever to the warning signal flap. This flap covers the breathing-bag connection in the valve assembly when the apparatus is not under pressure. If an attempt is made to breathe while it is without pressure, the air drawn from the breathing bag passes through slits in the flap covered by acoustic reeds. A clear musical note is then heard, warning the wearer that the bottle valve has not been opened.

As soon as the bottle valve is opened and the oxygen line pressurized, oxygen flows through an orifice to the bellows, compressing it so the warning signal flap is moved away from the breathing-bag connection.

Preflushing

When the oxygen bottle valve is opened, oxygen flows through the reducing valve to the preflushing unit. The pressure opens the control valve so that oxygen flows through the preflushing line into the circuit and fills the breathing bag. Simultaneously oxygen flows through an orifice into the diaphragm chamber of the preflushing unit. As soon as pressures are balanced on each side of the diaphragm, the valve is closed by spring pressure, thus completing the preflushing process. The preflushing unit functions so that a minimum of 6 litres of oxygen flows into the apparatus.

Manual Bypass Valve

Depressing the button of the manual bypass valve causes oxygen to flow from the high-pressure side of the oxygen control assembly directly to the preflushing line and from there into the circuit. This emergency oxygen supply is thus independent of the reducing valve, the demand valve and the constant-flow metering orifice.

Pressure Gauge and Gauge Tube

The gauge tube branches from the high-pressure side of the oxygen control assembly. The pressure gauge has luminous markings on the dial and needle so the bottle pressure can be constantly checked even in complete darkness. The gauge tube can be closed by a valve in the event of a leak in the tube or gauge.

TESTING PROCEDURE FOR DRÄGER OXYGEN BREATHING APPARATUS

Self-contained breathing apparatus must be tested before it is used; once the wearer is in a nonrespirable atmosphere it is too late to discover that the protective equipment is not functioning properly. The following 13-step procedure is suggested as **standard practice** for all persons preparing to use oxygen breathing apparatus; **it may save your life**. Similar procedures are applicable to other types of self-contained breathing equipment. You should pay particular attention to the testing sequence. It follows an efficient order, with each test leading to the next. Once you become familiar with the sequence you will find that there is a minimal amount of work involved. If the apparatus fails any of the tests, troubleshooting procedures are provided in Table 7-2.

Test 1: **Visual Inspection:** Take everything out of the carrying case, including the tool kit, and lay out the apparatus, facepiece and breathing hoses on the bench in front of you, with the back of the breathing apparatus facing you. Make sure you have antifog solution and wiping tissue for the facepiece ready to hand.

Inspect the apparatus and make sure that the protective cover and harness are in good condition. This includes examining all straps and metal fittings. When satisfied, lay the apparatus on its harness and remove the cover.

Test 2: **Check and Insert Oxygen Cylinder:** You must insert a fully charged oxygen cylinder if you are testing the apparatus just prior to wearing it, whether for training or actual rescue work. However, if you are making a routine monthly check on the apparatus and are **not going to wear it**, you may use a cylinder that is not fully charged, but is pressurized to **at least 14 atmospheres (1400 psi)**. If there is less pressure in the cylinder the test results will not be accurate.

Before connecting the cylinder to the oxygen control assembly, check the condition of the O-ring and screen in the hand-tight connection, and check the oxygen bottle for leaks by placing the bottle cap over the oxygen outlet, tightening the open bottle valve and immersing the valve assembly in water. Note any leaks then close the bottle valve and remove the cap. Immerse in water again to check for leaks in the bottle valve. Check the bottle for moisture by holding it horizontally and pointing the oxygen outlet toward a dry surface. Open and close the valve and note any moisture released from the bottle. Replace the bottle in the apparatus.

Test 3: **Insert Regenerative Canister:** If you are preparing to go into an actual rescue and are inserting a **factory-packed disposable canister**, you must first check to see that the string seal has not been broken and the canister has not expired. The expiry date is stamped on the factory label. You then unscrew and remove the inlet and outlet caps on the canister (with a wrench if necessary) and insert the canister in the holder. Make sure that the arrow on the canister is pointing in the same direction as the arrow on the holder.

Check the gaskets in the breathing-bag elbow sockets and then connect the sockets to the inlet and outlet of the canister.

If a refillable canister is used for training purposes or for routine testing, before filling it, check that the screens in the inlet and outlet of the canister are clean. Clean them with a brush and compressed air if necessary. Now completely fill the canister with absorbent chemical. Fill it a third at a time, shaking and tapping the canister after each third. This will settle all the chemicals, allowing no air spaces inside. Top off the canister as best you can – a scoop and funnel work well if you have them.

After checking the gasket in the plug connection, put the plug back into the canister and tighten it with the slotted wrench provided in the tool kit.

Again, when you place the canister in the holder, the arrows should point in the same direction. Check the gaskets before connecting the breathing-bag elbow sockets to the inlet and outlet of the canister.

Test 4: **Facepiece and Breathing Hoses Examination:** Examine the facepiece, breathing hoses and head harness to make sure they are in good condition. You should see no signs of deteriorated rubber, no cracks in the lens and no torn edges on the facepiece seal. Check the breathing hoses by holding your cupped hand partly over the connection of one hose and blowing through the other. Air should flow freely through the hoses. Check the hose connections to ensure that the O-rings have not been dislodged during cleaning, then attach the breathing hoses to the apparatus. The inhalation hose with the saliva trap goes on the bottom connection. Hand-tightened connections are satisfactory.

You are now ready to hook up the apparatus to the tester. Brief descriptions of Dräger testing units are provided later in this chapter.

Test 5: **Exhalation Valve Test:** First, zero-adjust the tester by turning the black adjustment knob in the lower left-hand corner. Do not readjust this setting for the rest of the testing. Next, remove the cover from the hose connection on the tester and screw in the breathing-hose adaptor, followed by the breathing hoses. This connection should be tight enough to prevent leakage.

To test the exhalation valve, cap off the exhalation hose and connect the inhalation hose (the one with the saliva trap) to the exhalation valve assembly on the apparatus. Set the tester on NEGATIVE-PRESSURE PUMPING and start to work the bellows with very gentle strokes (you should meet resistance at once). Watch the breathing bag. It should not begin to **deflate** after 5 seconds, indicating the exhalation valve is working properly; it only allows the wearer's **exhaled air** to pass into the apparatus, not back out to the atmosphere.

Test 6: **Inhalation Valve Test:** Next test the inhalation valve. Remove the hose from the exhalation valve and connect it to the inhalation valve, making sure that the saliva trap is in a vertical position before tightening the connection. This will ensure that the trap is in the proper position when you put on the apparatus.

Switch the selector knob to POSITIVE-PRESSURE PUMPING and pump gently. Again, watch the breathing bag. It should not **inflate** after 5 seconds; it only allows the wearer to **inhale** air from the breathing bag, and not exhale it back into the bag.

Test 7: **Relief Valve Test:** This test will show if the relief-valve vents as it should when the bag is overpressurized.

First, remove the cap from the exhalation hose and connect the hose to the apparatus at the exhalation valve. The tester should already be set on POSITIVE-PRESSURE PUMPING, so start pumping to fill the bag. When the bag is full, listen for the relief valve to open and try to feel the escaping air by wetting a finger and holding it in front of the vent. The valve should open when the meter reads between +10 and +40 millimetres water gauge (0.1 to 0.4 kPa). Watch the meter while testing.

Test 8: **Positive-pressure Leak Test:** Now you are ready to test for air leaking out of the apparatus. First, **seal the relief-valve vent** (in the lung-demand assembly) with the rubber plug provided in the tool kit. The tester should already be set on POSITIVE-PRESSURE PUMPING, so pump up the breathing bag until the meter needle reads + 100 millimetres water gauge (1 kPa) then switch the tester to LEAK TEST and bleed the needle down to +70 millimetres water gauge (0.7 kPa). Using a stopwatch, observe the needle for 60 seconds; it should not drop more than 10 millimetres water gauge (0.1 kPa).

Test 9: **Negative-pressure Leak Test:** You must now test for air leaking into the apparatus from outside. Remove the rubber plug from the relief vent. Switch the tester to NEGATIVE-PRESSURE PUMPING and pump the bellows until the meter reads − 100 millimetres water gauge. Continue as in Test 8. The needle should not rise more than 10 millimetres water gauge in 60 seconds.

Test 10: **Preflush Test:** This test checks to see that the automatic preflushing action fills the breathing circuit with oxygen and removes nitrogen as soon as the oxygen cylinder valve is opened.

With the plugs removed from the lung-demand valve and warning whistle, the breathing bag fully deflated, the tester set on NEGATIVE-PRESSURE PUMPING, all connections tightened, the breathing bag should fully inflate and the whistle should make a short chirp when the oxygen cylinder valve is opened.

If the bag does not fully inflate, repeat the test. If it still does not fully inflate, the entire oxygen control assembly must be returned to the manufacturer. Similarly, the assembly must be replaced if the preflushing device fails to close after flushing.

Failure of the apparatus in the preflush test means that harmful nitrogen has not been purged from the breathing circuit and the apparatus is unfit for use until the oxygen control assembly has been replaced.

Test 11: **Lung-demand Valve and Breathing-bag Volume Test:** Now that the bag is full, pump air out of the bag to find how much air it holds and how much negative pressure is needed before the demand valve kicks in. With the tester set on NEGATIVE-PRESSURE PUMPING, start pumping, count the strokes, and listen for the lung-demand valve to open. Each stroke draws approximately 0.5 litre of air so it should take at least 10 strokes before the bag deflates enough to open the demand valve. Watch the meter; it should read between 1 and 4 centimetres water gauge when the demand valve opens.

Test 12: **Bypass/Constant Dosage Test:** Now that the breathing bag is deflated, check to see that the manual bypass valve works to fill the bag in 10 seconds or less, then check to see how much oxygen is metered into the bag when the apparatus is functioning automatically.

Set the tester on the RED dosage test (0.5 to 2.0 litres per minute) and put the plug in the vent of the pressure-relief valve. Press and hold the red bypass valve and listen for the flow of oxygen into the breathing bag as it fills up. Release the bypass button when the meter reads 1.7 litres per minute on the outside red scale. The needle should then settle between 1.4 and 1.7 litres per minute, indicating that the dosage device is allowing about 1.5 litres of oxygen per minute to flow constantly into the breathing bag. [Note: the permissable dosage range will increase at higher elevations. For example, at 1800 metres (6000 feet) the permissible range is 1.5 to 1.8 litres per minute].

Test 13: **High and Medium-pressure Leak Tests:** You have now finished with the tester and are ready for the final test, checking the high and medium-pressure lines to find any leaks that have been indicated by the tester. With the cylinder valve still open, coat the high and medium-pressure lines and connections with soap suds or a leak-detector solution. Any bubbles will indicate a leak. Be sure to check:

- Bottle-valve connection and bottle valve.
- Gauge-line connection at the reducing valve.
- Gauge-line connection at the pressure gauge.
- Gauge-line shut-off valve.

This concludes the testing procedures. Close the cylinder valve unles you are continuing directly into training or rescue operations. In the latter event, continue as follows:

- **Prepare the Facepiece:** Squirt sufficient antifog solution onto the wiper inside the facepiece to soak it thoroughly, then turn the wiper back and forth four or more times to be sure that all the inner surface of the lens has been treated with solution. Put the facepiece back on the bench.
- **Put on the Apparatus:** (*see* section later in this chapter).
- **Preflush:** Open the main bottle valve fully, then close it half a turn. The preflush automatically takes place when 6 litres of oxygen is released and flows throughout the apparatus.
- **Put on the Facepiece:** Place the chin and nose in the spaces provided, then pull the straps over the head. Tighten the two neck straps, then the two temple straps.
- **Check for Airtightness:** To check whether there is a leak around the facepiece seal, or at the junction of the hose assembly and the facepiece, simply squeeze both breathing hoses while trying to breathe in and out. Inability to inhale or exhale indicates a good seal.

REGULAR PART REPLACEMENT

In addition to routine scheduled maintenance, replacement of certain parts of the apparatus is required at regular intervals. Provided accurate maintenance records are kept, there should be no difficulty in identifying parts that have reached the end of their service life. The maximum service lives of key components of Dräger breathing apparatus are listed below. Parts must be serviced or replaced at or before the time stated, never later. Naturally, if a part is damaged or wears out before its service life is up, it must be replaced immediately.

Other manufacturers provide similar information on the useful life of equipment components. Persons responsible for the care and maintenance of breathing apparatus should familiarize themselves with the preventative maintenance schedules recommended by the manufacturers of the equipment in their care.

After each use:

- Condition the leather wiper in the ZS facepiece with a suitable antifog solution after cleaning.
- Any time a copper gasket is removed from the apparatus, for whatever reason, it should be replaced with a new one to ensure proper sealing. **Do not reuse old copper gaskets**.
- When cleaning, inspect the breathing bag, breathing hoses and facepiece for stiffness, cracking and signs of aging.
- When cleaning, inspect the lung-demand diaphragm for damage and aging.

Every 6 months:

- Replace the O-ring at the oxygen cylinder connection.

Every 2 years:

- Replace all rubber or neoprene sealing rings.
- Put a new inhalation valve into the lung-demand assembly.

Every 3 years:

- Replace the lung-demand diaphragm.
- Discard spare rubber gaskets and sealing rings. Replace with new parts.

Every 5 years:

- The oxygen control group should be returned to the manufacturer for overhaul.
- The oxygen cylinder must be retested by a certified testing facility. (The test date, in month and year, is stamped on the cylinder).
- The breathing bag, breathing hoses and facepiece have a **minimum** service life of 5 years. If these items are still in good condition, they need not be replaced.
- The O-ring under the speaking diaphragm should be replaced. If the diaphragm appears worn, it also can be replaced at this time.

Every 6 years:

- The lung-demand valve assembly should be replaced.

TESTING INSTRUMENTS FOR OXYGEN BREATHING APPARATUS

THE RZ 35 NEGATIVE-PRESSURE TESTER

The RZ 35 from Dräger (Plate 7-15) is used to test compressed-air respirators and oxygen breathing apparatus. It gives a reliable indication of whether:

- The sets are leak-tight.
- The lung-demand regulators respond reliably.

Testing with the RZ 35 does not require any great expenditure, enabling the apparatus inspector to test sets more often; frequent testing increases safety.

The test unit is housed in a metal casing and consists of:

- A robust measuring instrument with expanded scale.
- A test socket with knuckle thread connection.
- An adaptor for changing to central connection.
- A suction-bellows pump, which creates the negative pressure.
- An air-vent valve.

The cylinder valves of the set to be tested are left closed. The set is vented and connected to the RZ 35. The suction-bellows pump creates the negative pressure for testing. The measuring instrument shows whether the test pressure (negative pressure) stays within the permissible limits and whether the lung-demand regulator responds before reaching the limit value.

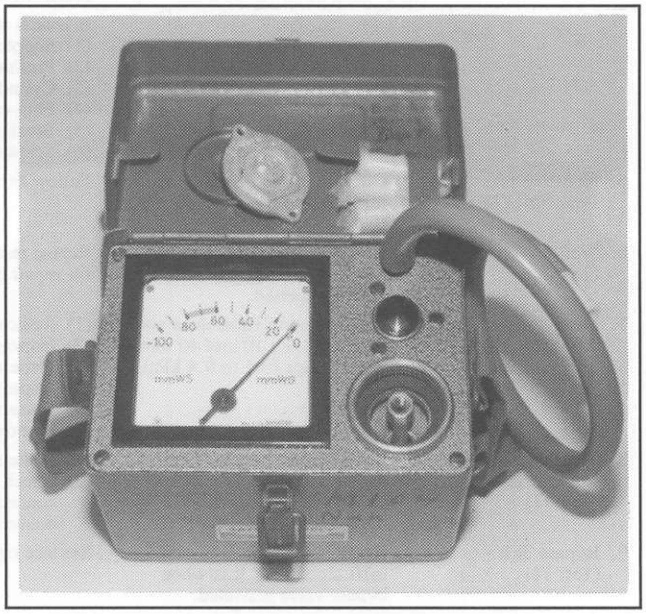


Plate 7-15. Dräger negative-pressure tester, Model RZ 35.

DRÄGER UNIVERSAL TESTER, MODEL RZ 25

The Universal Tester (Plate 7-16) is a multipurpose unit for the use in the testing of the Dräger BG 174 oxygen breathing apparatus and other similar types of breathing equipment.

When used for testing the BG 174, it will perform the following functions:

- Negative leak test.
- Operation of automatic-demand valve.
- Operation of constant-flow metering orifice.
- Positive leak test.
- Operation of relief valve.
- Operation of warning signal.

TABLE 7-2
TROUBLESHOOTING PROCEDURES FOR DRÄGER SELF-CONTAINED BREATHING APPARATUS

Test	Problem	What to Do
1. Exhalation Valve Test (Test 5)	Exhalation valve lets air out of the breathing bag.	Clean exhalation valve. If air still flows out of bag, replace exhalation valve.
2. Inhalation Valve Test (Test 6)	Inhalation valve lets air enter the breathing bag.	Clean inhalation valve. If air still flows into bag, replace inhalation valve.
3. Relief Valve Test (Test 7)	Pressure relief valve does not open when circuit pressure is between + 10 and + 40 mm water gauge (0.1 to 0.4 kPa).	Replace retaining spring in pressure relief valve.
4. Positive-pressure Leak Test (Test 8)	Circuit pressure drops more than 1 cm water gauge (0.1 kPa) in 60 seconds. Leak in apparatus.	Retighten: (1) Hose adaptor on the tester. (2) Screw-ring cover on lung-demand valve assembly. (3) Absorbing cartridge connections. (4) Plug on training canister. (5) Breathing bag. (6) Supplementary oxygen line connection at lung-demand valve. (7) Preflush line connection. (8) Cylinder connection. (9) Locking screw on saliva trap. (10) Breathing hoses. (11) Test plugs. (12) Cylinder valve. If leak persists, do a positive-pressure leak test on the breathing hoses and, if necessary, the breathing bag. If leak is still not located, replace O-rings and washers in order on these connections: (1) Supplementary valve line. (2) Preflush line connection. (3) Cylinder connection. (4) Plug-on training canister. (5) Breathing bag. (6) Screw-ring cover on lung-demand valve assembly.
5. Negative-pressure Leak Test (Test 9)	Circuit pressure rises more than 10 mm water gauge (0.1 kPa) in 60 seconds.	Follow same troubleshooting procedure as in Positive-pressure Leak Test.
6. Preflush Test (Test 10)	Breathing bag does not fully inflate when oxygen cylinder valve is opened.	Repeat test. If bag still does not fully inflate, return oxygen control group to manufacturer for repair or replacement.
7. Lung-demand Valve Test (Test 11)	Lung-demand valve does not open between 10 and 40 mm water gauge (0.1 to 0.4 kPa).	(1) Remove lung-demand assembly cover. (2) Inspect diaphragm for punctures. (3) Inspect valve head for seating. (4) Inspect set bolt for freedom of movement. (5) Inspect valve-pin lever to ensure arm is not bent. (6) If above parts check out properly, replace retaining spring.
8. Breathing-bag Volume Test (Test 11)	Lung-demand valve opens before 10 pump strokes are completed on tester.	(1) Make sure bag is full before retesting. Pump up bag until pressure-relief valve opens. (2) Check to see that bag is inserted properly (Dräger emblem faces outward), the connection at lung-demand valve assembly is correct and that bag is not twisted at that connection.
9. Bypass Test (Test 11)	Breathing bag does not inflate in10 seconds or less when bypass valve activated.	Replace oxygen control group and return malfunctioning unit to manufacturer.
10. Constant Dosage Test (Test 12)	Dosage does not fall within a range of 1.4 to 1.7 L/min on the red scale of the test gauge (at sea level).	First, check for proper functioning of the oxygen control group: (1) Remove preflush line from cartridge connection socket. (2) Remove breathing hoses and hose adaptor from tester. (3) Connect preflush line to tester with small diameter hose provided. Be sure apparatus is on and has preflushed before attaching hose. (4) Check dosage reading on tester gauge. A reading of 1.4 to 1.7 L/min means oxygen control group is functioning properly. If reading is outside this range, oxygen control group must be replaced. If oxygen control group checks out, check for low or high dosage reading. Low Dosage (less than 1.4 L/min) (1) Check all hand-tightened connections on apparatus and tester. (2) If low dosage continues, systematically replace O-rings and washers using same procedure as in Positive-pressure Leak Test. High Dosage (more than 1.7 L/min) (1) Close cylinder valve. After chest gauge reads zero pressure, lift pressure gauge shut-off lever and open cylinder valve. Reconnect preflush line to tester with small hose and read dosage. If dosage is now correct, high pressure is caused by a leak in whistle, which should be fixed. Return defective whistle to manufacturer. (2) If problem still exists, remove lung-demand assembly cover and inspect valve for leaks with soap or leak detecting solution. Replace tin washer with spare provided or replace complete valve, if necessary.
11. High and Medium-pressure Leak Test (Test 13)	Pressure leak in high or medium-pressure line or connection.	Retighten connection. If leak continues replace O-ring or gasket in connection and retighten; or replace complete assembly (i.e., medium-pressure line) if necessary.

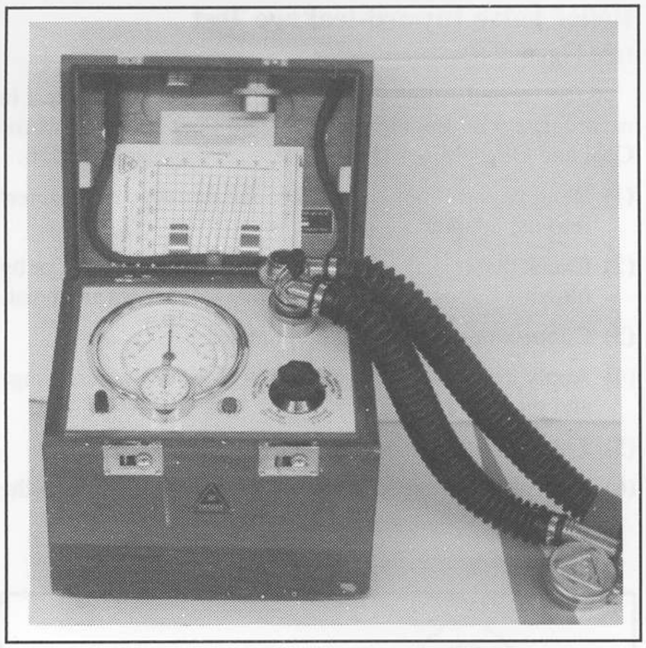


Plate 7-16. Dräger universal tester, Model RZ 25.

SIEBE GORMAN AERORLOX LIQUID OXYGEN BREATHING APPARATUS

Aerorlox is a 3-hour, closed-circuit, liquid oxygen breathing apparatus which provides cool dry air even when being used in a hot environment (Figure 7-8). Breathing resistance is so low that it is hardly noticeable under heavy work conditions. The rated duration of Aerorlox with a 2.9-kilogram (6.5-pound) charge of liquid oxygen is 3 hours with a 25 per cent safety factor at hard work rate. As the work rate decreases so the duration increases.

The warm, saturated exhaled air passes from the mouthpiece, through the exhalation valve housed within it, and along the exhale breathing tube into the purifying canister. When the air in the circuit reaches a pressure of 0.2 kilopascal (0.8 inch water gauge), any further exhaled air is discharged to the atmosphere through the automatic relief valve.

The exhaled air passes through the radial flow purifying canister where carbon dioxide is absorbed. The purified air passes over one end of the liquid oxygen pack into the breathing bag. This cools the air and condenses the moisture, which collects in the breathing bag.

The heat from the purified air surrounding the liquid oxygen pack stimulates the evaporation of oxygen. The oxygen gas passes from the innermost container to and fro through the outer cases and, by so doing, slows down heat input to the liquid oxygen. As the cool gaseous oxygen flows out of the evaporating tube, it mixes with the purified air in the breathing bag, further reducing the air temperature and condensing more of the moisture. The condensate falls into the breathing bag where it remains trapped.

Oxygen-enriched air from the breathing bag passes over the liquid oxygen pack between baffles to lengthen the path it travels and, in the process, it is further cooled. The cool, fresh, dry air passes along the inhale breathing tube and through the inspiratory valve into the mouthpiece.

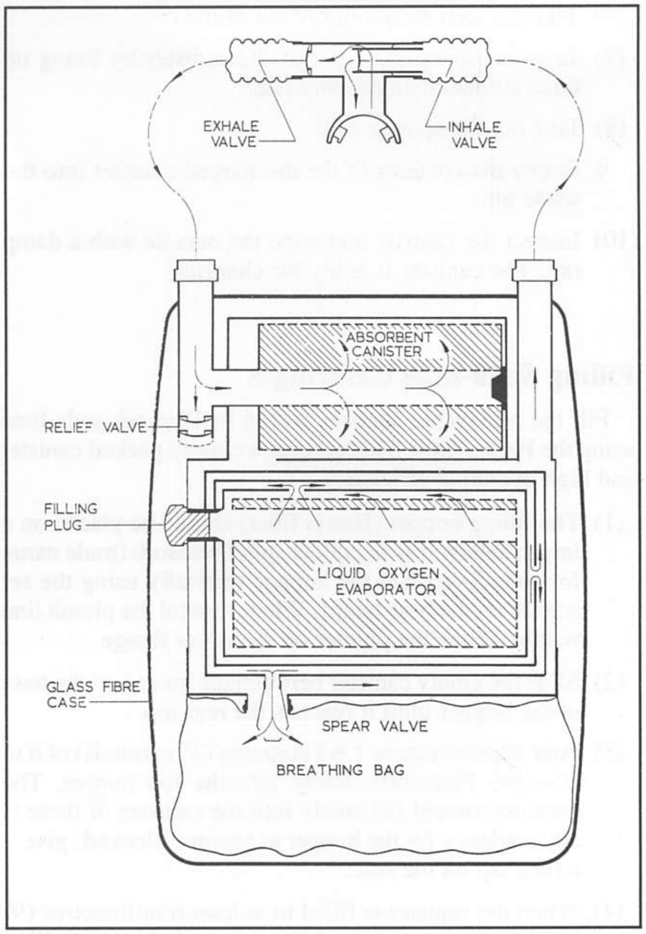


Figure 7-8. Cutaway diagram of Aerorlox liquid oxygen breathing apparatus.

Preparing the Apparatus for Use

The Aerorlox apparatus must be charged with soda-lime and, IMMEDIATELY BEFORE IT IS REQUIRED TO BE USED, with liquid oxygen. Once charged with liquid oxygen, it will begin to evaporate and should the apparatus not be used the oxygen will be exhausted in approximately 4 hours.

Replacing Soda-lime Canister

(1) Place the set (without the fibreglass case) on its side on the bench, with the end-cap facing upwards.

(2) Using the thumb of the left hand, pull off the bayonet spring to unlock it.

(3) Place the right hand on top of the end-cap and relief-valve assembly.

(4) Depress the end-cap assembly and turn it clockwise to disengage the bayonet pins (steady the set with the left hand holding the spring in the withdrawn position).

(5) Place the end-cap assembly on the bench.

(6) Take the canister assembly out of the case.

(7) Take the clamp-plate out of the canister by lining up three cutouts with canister lugs.

(8) Take out the sponge pad.

(9) Empty the contents of the discharged canister into the waste bin.

(10) Inspect the canister and wipe the outside with a damp rag. The canister is ready for charging.

Filling Soda-lime Cartridges

Fill the removable canister with 6 to 10-mesh soda-lime using the Harris filler. This ensures a closely packed canister and high operating efficiency.

(1) The filling hopper (Harris filler) should be placed on a large shallow tray to collect split Protosorb (trade name for soda-lime). Set the hopper vertically using the set screws on the base board. When vertical the plumb line will be above the pointer on the lower flange.

(2) Slide the empty canister between the guides on the base of the hopper until it reaches the rear top.

(3) Pour approximately 1.6 kilograms ($3^{1}/_{2}$ pounds) of 6 to 10-mesh Protosorb slowly into the top hopper. The granules should fall freely into the canister. If there is any tendency for the hopper to become blocked, give it a firm tap on the side.

(4) When the canister is filled to at least 6 millimetres ($^{1}/_{4}$ inch) from the top, carefully remove it from the filler, taking care not to disturb the Protosorb.

(5) Place the plough on top of the Protosorb and rotate it until it bottoms on the centre spindle.

(6) Remove the plough, insert the sponge pad and the clamp-plate and spring on the top of it. Depress it slightly and turn it around to engage the three webs under the lugs of the canister (the spring holds the charge firm and takes up any settlement during use). The canisters, once charged, may be inserted in the apparatus or held in special storage cans ready for immediate use.

(7) Before inserting the end-cap which holds the relief valve in the case, wipe the U-seal, the rim of the outer case (inside) and the O-ring seal inside the tube, with a damp rag to remove any particles of soda-lime.

(8) Also check that the rubber washer at the far end of the case is in place and in good condition.

(9) Withdraw the spring on the rim of the outer case (using the thumb of the left hand) and place the end-cap in position, engaging on the three bayonet pins. Holding the right hand on top of the cap assembly, depress it and turn clockwise to fully engage the bayonet pins.

(10) Release the spring so that it locks the bayonet plug in position. Before charging the set with liquid oxygen do the leak test on the relief valve then the wet test (Figures 7-10 and 7-11).

Relief Valve Inward-leakage Test

(*see* Figure 7-9)

To be carried out on each occasion prior to the wet test in accordance with Regulation 25(4) and First Schedule of the Coal and Other Mines (Fire & Rescue) Regulations 1956.

(1) Remove the relief valve from the apparatus and screw into the adaptor.

(2) Check that it is clean, either by washing it in water or by blowing through it, and ensure that valve discs are moist.

(3) Connect one tube to the manometer.

(4) Apply a suction of 5 centimetres (2 inches water) gauge and pinch the tube.

(5) The water column should not fall.

(6) If there is a leak, recheck all points, blow through the valve to check it is clear, and retest.

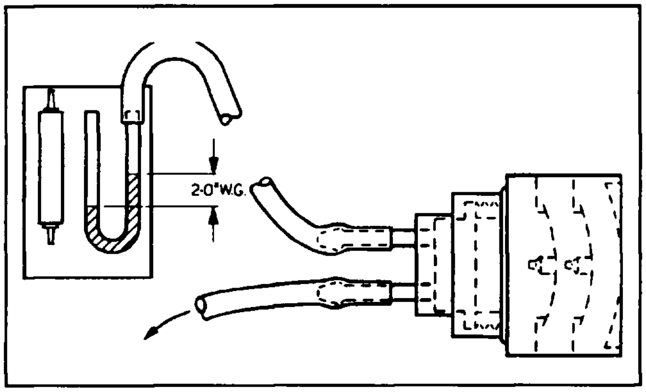


Figure 7-9. Relief valve inward-leak test.

"Wet Test" Procedure

The purpose of this test is to make sure that there are no leaks from the set when pressurized to 3 kilopascals (12 inches water gauge) (Figure 7-10).

(1) After charging and replacing the soda-lime canister in position, check all connections for tightness and correct positioning:

  (a) exhale-tube connection (between corrugated exhale tube and soda-lime canister and cap tube) by tightening the round knurled nut;

  (b) inhale-tube connection (between corrugated inhale tube and outer case liner) by checking its correct engagement and tightening the round nut;

  (c) breathing-bag connection (between breathing-bag neck and outer-case liner) by checking its correct engagement and tightening the round nut;

  (d) correct locking and bayonet pins engagement;

  (e) relief-valve seal by turning its case clockwise;

  (f) filler plug by tightening it.

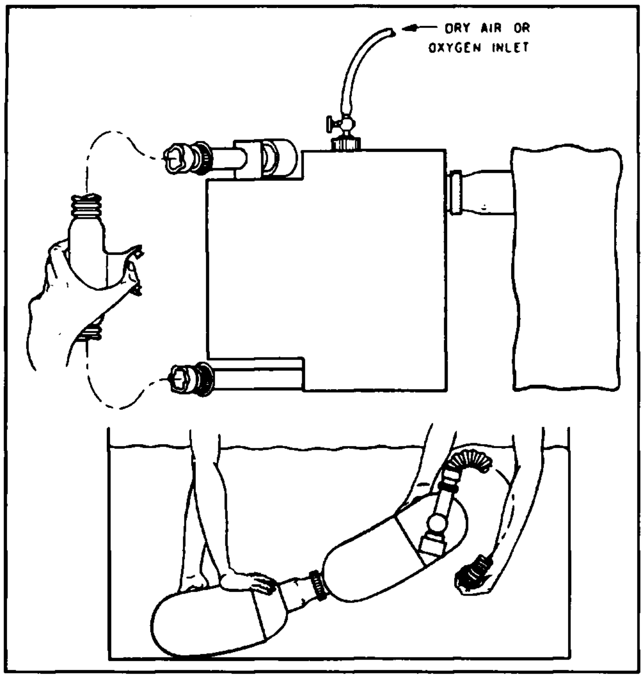


Figure 7-10. Wet test procedure for outward leaks

(2) Unscrew the perforated relief-valve cap and replace it with the solid one with O-ring inside (specially provided).

(3) Plug the mouthpiece using the rubber bung with a metal liner (specially provided).

(4) Connect the liner to the low-pressure air line with the water gauge column in line (0 to 75 centimetres; 0 to 30 inches).

(5) Pressure the circuit to 3 kilopascals (12 inches water gauge).

(6) Watching the water column to maintain the pressure, immerse the set in a tank of water and check if there are any leaks.

(7) Take the set out and dry it with a clean rag.

(8) Replace the perforated relief-valve cover.

(9) Take the rubber bung out of the mouthpiece.

(10) Place the set back in the fibreglass case, remembering to lock the turnbuckles.

The set is now ready to be charged with liquid oxygen.

Charging Set with Liquid Oxygen

As soon as the liquid oxygen has been poured into the evaporator, the apparatus automatically begins to supply oxygen to the breathing circuit. The period for which the Aerorlox set may be used starts from this moment and is normally 2 hours. The procedure for charging the set with oxygen is:

(1) Open the lid of the apparatus by undoing the bottom catch.

(2) Place the apparatus on its side on the flat weighing scale and support it by balancing the lid on the top hinges (if a spring balance is used, suspend the set on the bar provided for it).

(3) Remove the plug from the liquid oxygen pack.

(4) Insert the filling funnel into the filling hole.

(5) NOTE THE WEIGHT ON THE BALANCE AND CAREFULLY POUR IN LIQUID OXYGEN UNTIL THE SCALE SHOWS 2.9 KILOGRAMS (6½ POUNDS) MORE THAN THE INITIAL READING. IF THE SET WILL ONLY BE USED FOR A 2-HOUR PERIOD, THEN IT IS ONLY NECESSARY TO FILL WITH 2.5 KILOGRAMS (5½ POUNDS) OF LIQUID OXYGEN.

(6) Remove the funnel and replace the filling plug. Screw it down tightly. Do this at once or else ice will form on the threads and make closure difficult.

(7) Stand the set up and close the lid by securing the bottom catch.

The set is now ready for use.

(1) Put the set on and adjust the harness to fit comfortably.

(2) Insert the mouthpiece and put on the nose clip while breathing through the mouth only.

(3) REMEMBER TO CHECK THE TIME, SO AS NOT TO OVERRUN THE WORKING PERIOD OF THE SET. THIS IS A MAXIMUM OF 3 HOURS.

ROUTINE MAINTENANCE

Cleaning

Each time the set is used, all parts of the breathing circuit should be washed in water with disinfectant. The cleaning procedure is:

(1) Remove the set from the fibreglass case and disconnect the breathing tubes and breathing bag.

(2) Take out the purifying canister and empty out used Protosorb.

(3) Remove the spear valve from the evaporator outlet and screw in the test adaptor with red rubber tube. Seal the open end of the tube with the attached plug. Check that the red liquid-oxygen filler-plug is securely fixed on.

Note: It is important to prevent water entering the evaporator itself. If water does enter the evaporator, the apparatus should be reweighed and compared with the weight engraved on the plate. If the increase in weight exceeds 115 grams (4 ounces), the apparatus should be returned to Siebe Gorman. If the weight increase is less than 115 grams, the apparatus should be heated in an oven at a maximum temperature of 130°C (265°F) for 24 hours, after which time the weight must be within 28 grams (1 ounce) of that stated.

(4) The various parts of the breathing circuit may now be washed in water containing disinfectant. Stand the set on a suitable bench to drain.

(5) The breathing tubes and breathing bag should be washed carefully and then hung up to drain and dry.

(6) The relief valve must only be unscrewed, not disassembled. The only cleaning necessary is to pour fresh water through it.

NOTE: DO NOT USE STRONG DETERGENT OR SOAP SOLUTION TO CLEAN THE MICA RELIEF-VALVE DISC. USE ONLY CLEAN WATER AND A CAMEL-HAIR BRUSH.

Recharging Purifying Canister Using Hopper

The hopper is used for charging the purifying canister with Protosorb following the procedure outlined under "Preparing the Apparatus for Use" (page 104). This method ensures that the granules are closely packed to give highest efficiency.

PERIODIC MAINTENANCE

Relief Valve Pressure Test

(Figure 7-11)

Frequency – intervals not exceeding 30 days.

(1) Remove the relief valve assembly from the lid of the purifying canister.

(2) Check that it is clean, either by washing in water or by blowing through it; ensure that the valve discs are moist.

(3) Screw into test adaptor, connect one tube to a manometer and the other to the top of the flow meter.

(4) Pass a flow of 1 litre per minute through the moist valve using an auxiliary supply of air or oxygen.

(5) The pressure on the manometer should be between 0.2 and 0.4 kilopascal (0.8 to 1.6 inches water gauge).

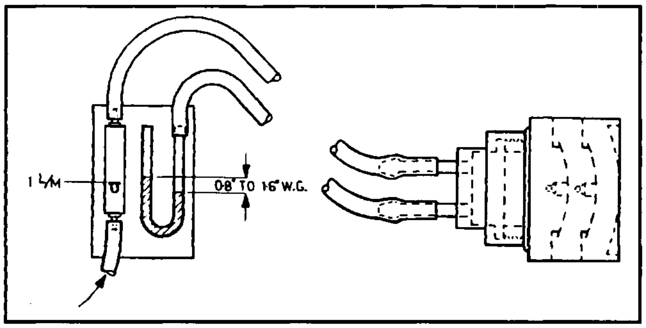


Figure 7-11. Relief valve pressure test.

Leak Testing of Evaporator

(Figure 7-12)

Frequency – intervals not exceeding 30 days.

This test must not be carried out with liquid oxygen in the apparatus.

(1) Remove the set from the fibreglass case and disconnect the breathing bag.

(2) Unscrew the spear valve at the bag connection and fit the test adaptor.

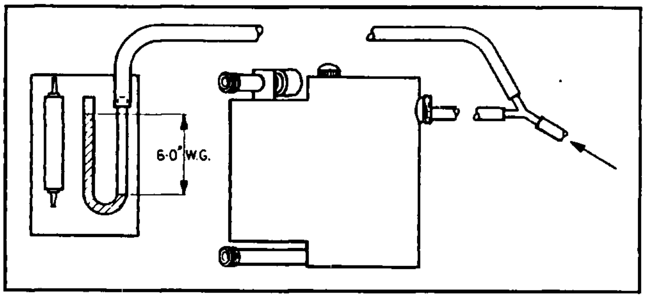


Figure 7-12. Leak test on evaporator.

(3) Connect to the manometer using the "Y" piece provided (Figure 7-9).

(4) Blow down the tube and pressurize the evaporator to 1.5 kilopascals (6 inches water gauge). Pinch the end of the tube.

(5) The pressure should not fall.

Evaporator Flow Check after Wearing

Frequency – test after wearing for 2 hours and at least once every 30 days during which the apparatus has been worn.

(1) At the end of a practice run on the apparatus remove the breathing bag and evaporator from the case.

(2) Remove the breathing bag and evaporator spear valve, screw in the test adaptor with 1-metre (3-foot) length of red rubber hose and stand the evaporator on its side on the bench.

(3) Connect the red tube to the bottom of the flow meter.

(4) The flow of oxygen shall not be less than:
4 litres per minute 2 hours after filling,
2 litres per minute 2½ hours after filling.

Evaporator Full Flow Check

(Figure 7-13)

Frequency – every 6 months.

(1) With the breathing bag and evaporator spear valve removed, screw in the test adaptor with 1-metre (3-foot) length of red rubber hose.

(2) Fill the apparatus with 2.5 kilograms (5.5 pounds) of liquid oxygen.

(3) Stand the set upright on the bench.

(4) Connect the red tube to the bottom of the flow meter.

(5) The flow rate of oxygen shall not be less than that shown in Figure 7-13.

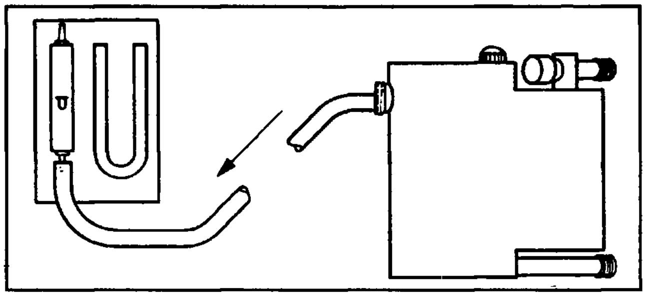


Figure 7-13. Evaporator full-flow check.

GENERAL NOTES ON THE APPARATUS

The oxygen flow from the apparatus is normally in the range of 8 to 12 litres per minute when in use. The flow rate is higher than this for 15 minutes after filling.

- The breathing bag has a capacity of about 6 litres when measured from +2.5 centimetres (+1 inch) water gauge to −2.5 centimetres (−1 inch) water gauge.

- The relief valve operates on almost every breath, as the flow of oxygen is well in excess of the body's requirements and the breathing bag is completely full.
- The inspired air is coldest approximately 5 to 7 minutes after charging, as it takes this amount of time to cool the set.
- The temperature of the inspired air, as it enters the mouthpiece, never exceeds 30°C (86°F) during the rated service time of the apparatus under test conditions in all ambient temperatures up to 30°C.
- At 30°C ambient air temperature, the inspired air temperature reaches about 23°C (73°F) after 30 minutes from about 0°C (32°F) after 5 minutes, and then gradually increases to about 28°C (82°F) after 2 hours. For lower ambient temperatures these figures are slightly lower, but are not significantly affected by changes in the ambient temperature.
- Excessive exertion tends to reduce the temperature of the inspired air. Because of this relationship the wearer loses body heat to the apparatus and so is able to endure hot environments for a longer period.
- The liquid oxygen pack is filled with asbestos wool which absorbs the liquid so that it does not spill into the outer chamber of the pack or into the breathing bag.
- Under operating conditions no part of the apparatus is pressurized in excess of 0.6 kilopascal (2.5 inches water gauge).

PUTTING ON SELF-CONTAINED BREATHING APPARATUS

The **over-the-head** method of donning breathing apparatus is particularly safe and is outlined here as a recommended method. "Switchable" pressure-demand and "continuous" pressure demand may be donned in a slightly different manner. The firefighter is directed to the manufacturar's recommendations for their particular equipment.

There are several steps involved in donning the apparatus:

Step 1 Turn coat collar up before donning;

Open the storage case or truck compartment and check the air cylinder gauge to make sure the air cylinder is full;

Step 2 Remove helmet and place facepiece in helmet to keep both together. This helps to prevent forgetting the helmet;

Grasp the back plate or cylinder with both hands, one at each side. There should be no straps between the hands and the cylinder;

Step 3 Lift the breathing apparatus from the case or compartment and let the regulator and harness hang free (Plate 7-17);

Raise the cylinder overhead, shake the unit to free harness and straps. Keep the elbows close to the body to allow the straps to fall easily into place. When properly positioned the cylinder valve will be located near the waist;

Step 4 Lean slightly forward and fasten the chest buckle, if the unit has one;

Pull down on the two underarm straps (Plate 7-18);

Plate 7-17. Putting on breathing apparatus; the over-the-head method. Step 3: raise the cylinder overhead and let the elbows find the loops in the shoulder harness.

Plate 7-18. Putting on breathing apparatus; the over-the-head method. Step 4: lean forward then pull down on the underarm straps.

Plate 7-19. Putting on breathing apparatus; the over-the-head method. Step 5: fasten and adjust the waist strap.

Plate 7-20. Putting on breathing apparatus; the coat method. Step 2: grasp the shoulder strap with one hand.

Plate 7-21. Putting on breathing apparatus; the coat method. Step 3: lift up and put on the apparatus like a coat.

Step 5 Fasten and adjust the lower waist strap so the unit fits snugly (Plate 7-19).

The "Coat-Method" of donning breathing apparatus is quick and safe and is outlined here as a recommended procedure. As with the "over-the-head" method, "switchable" pressure demand and "continuous" pressure demand may be donned in a slightly different manner. If in doubt, the firefighter is directed to the manufacturer's recommendation for their particular equipment.

There are several steps involved in donning the apparatus. The breathing apparatus may be donned like a coat, putting one arm through the shoulder strap loop. Then the second arm will be put through the other shoulder strap loop and secured to the body.

Step 1 Turn coat collar up;

Open the case or compartment and check the air cylinder gauge to make sure the air cylinder is full;

Step 2 Remove the helmet and place facepiece in the helmet to keep both together. This will help to remember the helmet;

With the right hand grasp the shoulder strap that will be worn over the right shoulder. (Alternative: left hand, left strap.) Bear in mind that when the unit is in plac on the firefighter's back, the cylinder valve will be at the bottom, near the waist (Plate 7-20).

Step 3 Bring the unit up so the strap rests on the shoulder. During this move the elbow of this arm should slip between the shoulder strap and the backpack frame;

As the unit swings across the back, the opposite arm should be inserted through its strap opening (Plate 7-21).

Step 4 Bend forward and slide the straps up to the shoulder;

Lean slightly forward and fasten the chest strap and/or adjust the shoulder straps to a snug, comfortable fit;

Step 5 Fasten and adjust the waist strap.

DONNING THE FACEPIECE

The firefighter must be familiar with the equipment that his fire department uses. Follow manufacturer's instruction for the correct procedure for donning a face mask.

The facepieces for self-contained breathing apparatus are all donned in a similar manner. One important difference is the number of straps that each facepiece utilizes.

Note: Facepieces, or any other part of the breathing apparatus, must not be interchanged amongst different makes or models. The facepiece must be worn snugly in order that it will seal against the face. Firefighters should not have long sideburns and beards that will interfere with the outer edge of the facepiece making a good seal againstk the skin. A facepiece must not be tightened too much, otherwise it will cut off the circulation and be uncomfortable.

(1) Donning The Two Strap Facepiece:

Plate 7-22. Breathing apparatus mounted in a convenient compartment on a pumper truck.

Plate 7-23. Putting on compartment-mounted breathing apparatus. The method will depend on how the equipment is mounted.

Plate 7-24. Putting on the facepiece. Step 3: grasp the harness and spread the straps.

Step 1 Hold the mask in your left hand; then with your right hand pull the hair net and headstrap assembly over the front of the facepiece;

Step 2 Set the chin into the chin cup, wipe the forehead hair from the seal area and push the mask against the face;

Step 3 With the free hand, grasp the hair net and head strap assembly and pull it across the top and back of the head (Plate 7-22).

Step 4 Smooth the hair net down and pull the two straps backwards (not outwards) evenly and simultaneously (Plate 7-23);

Step 5 Don the helmet and make certain that the helmet strap is under the chin and not on the facepiece (Plate 7-24);

Step 6 Check to make sure the red gasket is in place around the regulator outlet port. Put the red purge valve in the upward position against the facepiece; push inwards and give the regulator a quarter turn to the left to secure it to the facepiece. Listen for the "click" which indicates that regulator is in operating position;

Step 7 Check the facepiece seal by breathing in to slightly collapse the facepiece. If there is evidence of leaking, adjust or re-don the facepiece. If the facepiece seal cannot be obtained, the firefighter must not enter the hostile atmosphere.

(2) Donning The Four OR Five Strap Facepiece:

Step 1 If the firefighter is using the nomex hood, the hood should be donned before the facepiece. Put the hood over the head and pull the hood back and down so the face opening is around the neck;

Step 2 Grasp the head harness with the thumbs through the straps from the inside and spread the harness;

Step 3 Push the harness up the forehead to brush hair from the seal area. Continue up and over the head until the harness is centered at the rear of the head and the chin is in the facepiece chin up;

Step 4 Tighten the bottom straps by pulling them evenly and simultaneously to the rear. Do not overtighten the straps;

Step 5 Tighten the temple straps next;

Step 6 Tighten the top strap or straps;

Step 7 Check the facepiece seal. Block the airhose or air inlet with the hand and inhale deeply and slowly. If there is evidence of leakage, adjust or re-don the facepiece. If the facepiece seal cannot be obtained, the firefighter must not enter the hostile atmosphere;

Step 8 Check the exhalation valve. Inhale, then seal the end of the low pressure hose, and exhale. The exhalation should go through the exhalation valve. If the exhalation does not go through the exhalation valve, the unit should be removed from service and tagged for repair;

Step 9 If wearing a nomex hood, pull the hood into place, making sure all exposed skin is covered and that vision is not obscured;

Step 10 Don the helmet by first inserting the low pressure hose through the helmet's chin strap. With the helmet on the head, be sure that the helmet strap is under the chin, not around the lens or under the exhalation valve or any part of the facepiece. If this precaution is followed, a blow to the helmet will not dislodge the facepiece;

Step 11 Connect the low pressure hose to the regulator. If the unit is a switchable type, turn the switch to the "use" or "on" position. If the unit does not have a switch, open the cylinder valve. Be sure the mainline valve is fully open and the bypass (or purge) valve is fully closed on both types of units;

Step 12 Re-check the face seal by listening for the flow of air through the regulator while holding breaty. Breathe normally.

GETTING UNDER "AIR"

Step 1 If the unit is a "switchable" pressure demand type, switch the unit to the "don" or "off" position. Open the cylinder valve and check the regulator gauge. Both the cylinder gauge and the regulator gauge should register about the same. When the cylinder is turned on, the low pressure warning alarm may sound and then stop. If this alarm continues to sound, remove the apparatus from service and tag for repair;

N.B. Check the manufacturer's specifications for your own equipment to determine if the alarm device should sound when the cylinder valve is first opened.

Step 2 If the unit is a "continuous" pressure demand type, leave the cylinder valve closed at this time;

Step 3 Don the facepiece;

Step 4 Check the facepiece seal

(a) "Switchable" pressure demand type — block the air hose or air inlet with the hand and breathe inwards. If the facepiece seal is good, the mask will move in towards the face. If the facepiece seal is not air tight, then the mask **will not** move in towards the face.

(b) "Continuous" pressure demand type — block the air hose or air inlet hose with the hand, or the regulator, and breathe inwards. If the facepiece seal is air tight, then the mask will move in towards the face. If the facepiece seal cannot be obtained, the firefighter must not enter the hostile atmosphere;

Step 5 When the facepiece seal is achieved, don the helmet and then connect the low pressure hose between the facepiece and the regulator;

Step 6 With the "switchable" pressure demand turn the switch to the "on" or "use" position;

Step 7 With the "continuous" pressure demand regulator open the cylinder valve. When the cylinder valve is turned on, the low pressure warning alarm may sound, and then stop. If the alarm continues to sound, the equipment must be tagged and taken out of service;

N.B. Check the manufacturer's specifications for your own equipment to determine if the alarm device should sound when the cylinder valve is first opened.

Step 8 Re-check the face seal by listening for the flow of air through the regulator while holding your breath. Breathe normally;

Step 9 Check the regulator valve or remote pressure reading gauge occasionally for remaining air supply. Allow sufficient time to leave the contaminated area;

WARNING: When the low pressure warning alarm sounds, it warns the user that approximately 20% – 25% of the air supply remains. On some models this low pressure alarm also indicates a malfunction in the regulator. Check the manufacturer's instructions for the unit you are using. In both cases when the low pressure warning alarm sounds, the firefighter and his buddy must both leave the contaminated area at once.

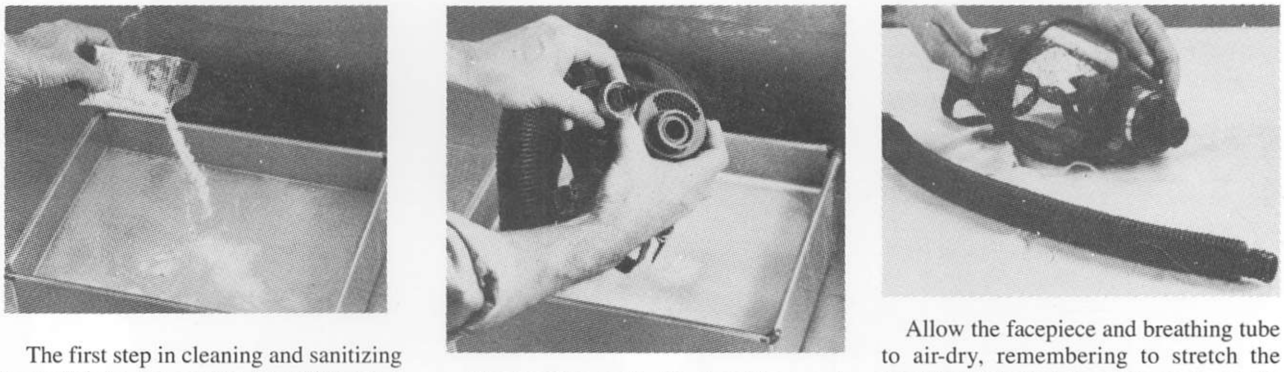
INSPECTION AND CARE OF SELF-CONTAINED BREATHING APPARATUS

Breathing apparatus must be inspected immediately after use. Each component of the Unit is checked; cylinder pressure, facepiece and breathing tube wear and cracking, including the exhalhation valve and speaking diaphragm and other parts for damage.

Then the apparatus is cleaned, disinfected and dried (Figure 7-14).

PERIODIC INSPECTION AND CARE

Inspect, clean and service equipment in accordance with the manufacturer's recommendations.



The first step in cleaning and sanitizing the unit is to remove the breathing tube. Do not lose the gasket inside the coupling nut on the breathing tube and the facepiece.

Thoroughly wash the facepiece and tube in a cleaner-sanitizer solution. A soft brush or sponge can be used to scrub the soiled facepiece and clean the tube.

Allow the facepiece and breathing tube to air-dry, remembering to stretch the breathing tube to release excess water. Do not attempt to force-dry the parts by placing them near a heater or in direct sunlight because the rubber will deteriorate.

Figure 7-14. Facepieces and hoses must be cleaned, sanitized and properly dried.

CHAPTER 8

MINE VENTILATION AND FIRE SUPPRESSION UNDERGROUND

TRAINING OBJECTIVES

Underground mine fires are an extremely hazardous situation with the potential for catastrophic loss of life and damage to the mine workings that may result in mine closure and the attendant loss of jobs. Fire suppression underground requires particular skills and a solid understanding of the basic principles of mine ventilation. Even greater care is needed than in the case of surface fires to avoid rescue workers becoming victims themselves. The objectives of this chapter are to familiarize rescue trainees with the principles of underground mine ventilation and instruments used to measure air flow, to familiarize them with mine plans and sections, and to provide training in the specialized techniques of underground firefighting.

Students must understand:

- **Why air moves in a mine.**
  - natural ventilation.
  - mechanical ventilation.
- **How to use instruments to measure mine ventilation.**
  - mine water gauge.
  - anemometer.
  - velometer.
  - thermometer.
  - barometer.
- **The term "mine resistance".**
- **Underground firefighting methods.**
  - direct attack; the use of foam.
  - temporary and permanent sealing.
  - when and how to unseal a mine fire.
- **Rescue procedures following a mine explosion.**
  - establishing the "fresh-air base".
  - how to explore ahead of fresh air.

UNDERGROUND MINE VENTILATION

The British Columbia mining laws require that sufficient quantities of fresh air be distributed throughout the workings of a mine so that gases and dust in the air that underground workers breathe are kept to a safe level. Harmful dust in the air must be below a specified number of particles per cubic metre of air and all gases in the air must be below the threshold limit values set by the American Conference of Industrial Hygienists.

The mine ventilation system must therefore be designed so that an adequate volume of fresh air is delivered to all working places and gases and dust are removed or are diluted to a safe level.

WHY AIR MOVES IN A MINE

When an air valve in a mine is opened, the higher pressure in the air line causes the air to rush out to the lower pressure environment outside the air pipe.

Television weather forecasters often report that a warm front or a cold front is approaching and that windy conditions can be expected as the front passes. A weather front is simply the contact line between an area of high pressure and an area of low pressure. The wind we experience at a weather front is the air in the high-pressure area rushing towards the low-pressure area.

Horizontal air movements are caused by differences in air pressure with the air always moving from a high-pressure area to an area of lower pressure. A fan, an aeroplane propeller, evening breezes, hurricanes, a draughty room and air moving in a mine are all examples of this. The greater the pressure difference the faster the air will move.

A difference in relative weight also causes air to move, but movements caused by differences in weight are in the vertical direction. Hot air is lighter than cold air and rises; cold air is heavier and will sink to lower places.

NATURAL VENTILATION

Many mines, especially in mountainous country, have natural ventilation caused by differences in pressure inside and outside the mine and by differences in the relative weight of warm and cold air. Consider the simple mine section shown in Figure 8-1. If the outside air is warmer than the air in the mine, the air will begin to flow out of the lower mine openings.

The outside air being warmer will be less dense and thus will have a lower pressure and relative weight than the cool air inside the mine. The denser and thus higher pressure air in the mine will tend to flow out of the lower mine openings to the low-pressure area outside. As the air in the mine flows out of the lower openings it must be replaced, otherwise a vacuum would be created in the mine. The outflowing air is replaced by warm air entering the upper mine workings. As the warm outside air enters the upper openings of the mine it is cooled by contact with the rock in the mine. Once cooler than the outside air it will continue to flow down through the mine to the lower openings.

The reason the air flows is because of a pressure difference inside and outside the mine. The direction of flow (downwards) is due to the heavier air's tendency to seek a lower elevation. If air outside the mine is warmer than air in the mine, the natural ventilation will be downwards and the lower mine openings will be outcast (*see* Figure 8-1).

The reverse situation occurs when the outside air is colder and thus at a higher pressure than warm mine air. The high-pressure air outside will flow toward the lower pressure

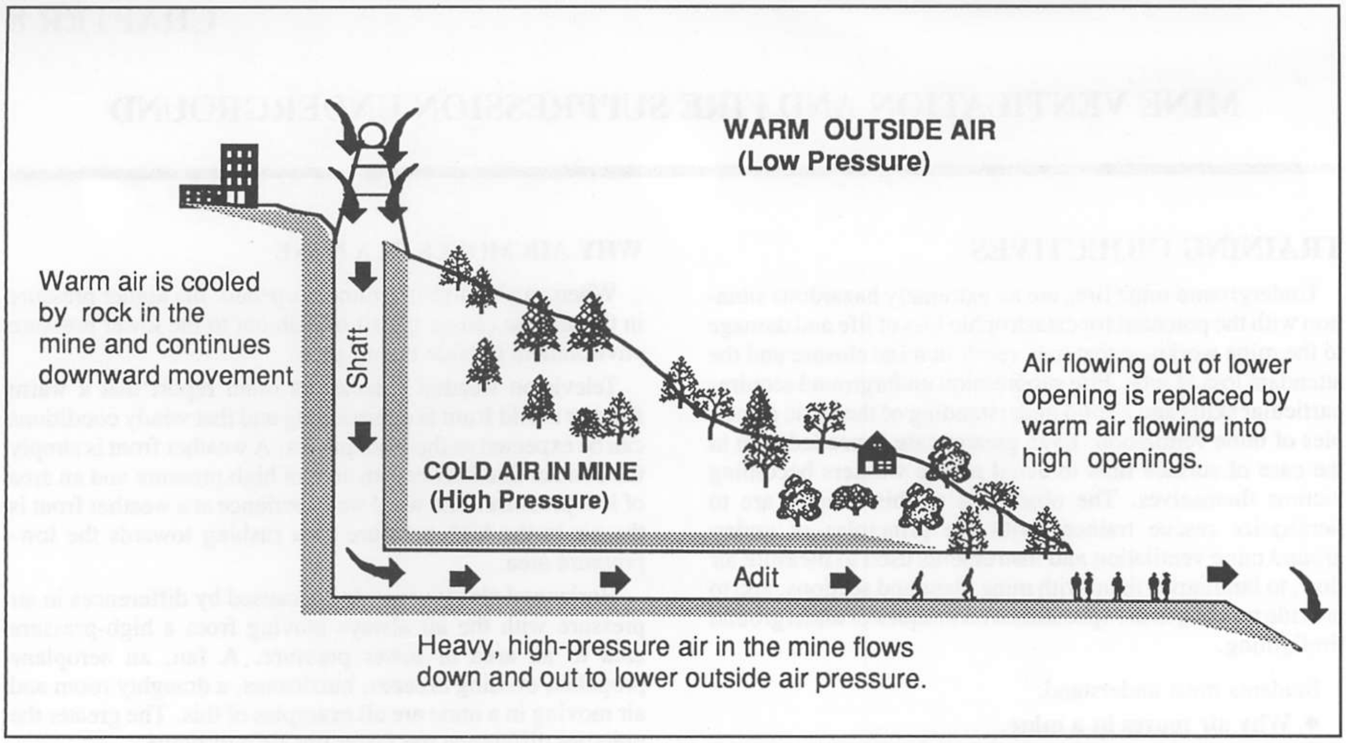


Figure 8-1. Downcast natural ventilation where mine air is cooler than the outside air.

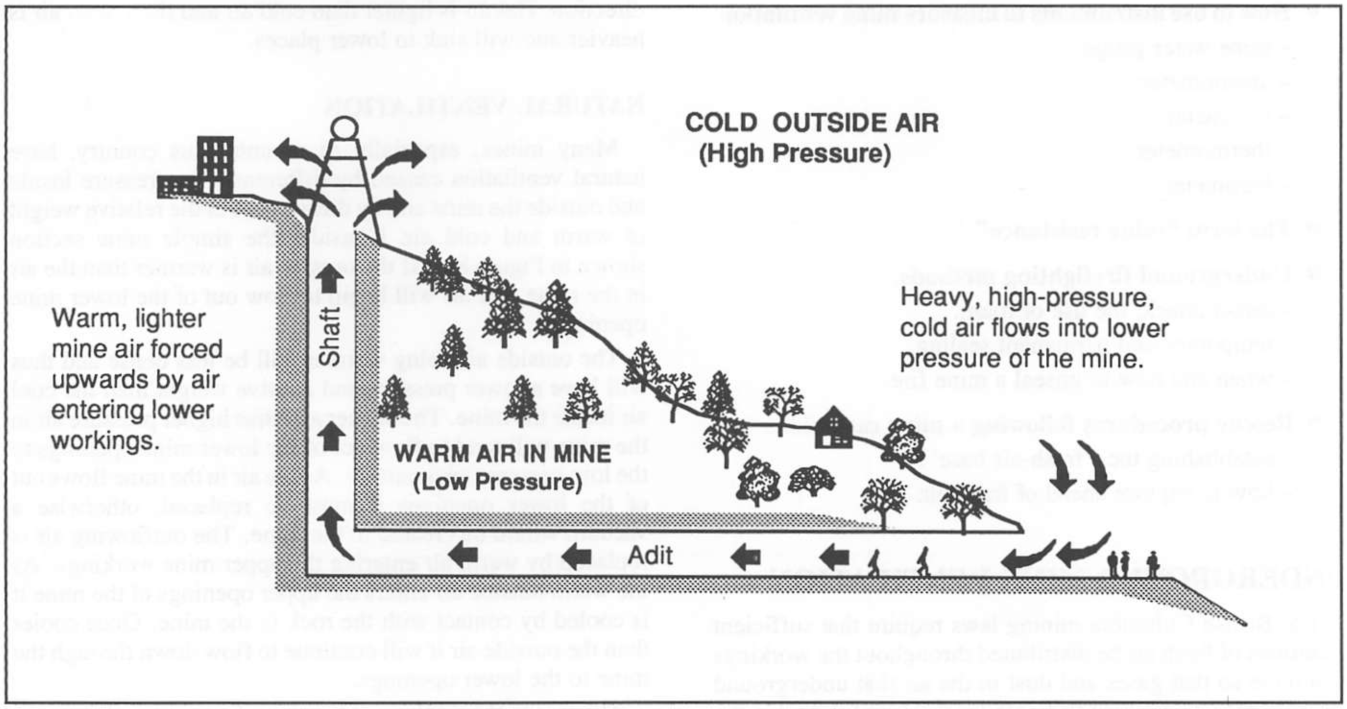


Figure 8-2. Upcast natural ventilation where mine air is warmer than outside air.

inside the mine. As the warm mine air tends to seek a higher elevation, the flow will be upwards. The lower openings will therefore be incast and the upper openings will be outcast (*see* Figure 8-2).

Natural mine ventilation, when it occurs, can be very effective, however, it is not reliable. If the outside air temperature changes and becomes the same as the mine air, then the air flow will stop. If outside air changes from warmer than mine air to colder than mine air, the ventilation will reverse.

It is quite common to have natural ventilation flows in one direction during the summer months and in the opposite direction during the winter. At certain times of the year (usually during the spring and fall) daily temperature variations can cause ventilation reversals within a few hours. Mines may be upcast at night and downcast during the day.

MECHANICAL VENTILATION

If natural ventilation cannot be relied upon to provide adequate ventilation then mechanical ventilation must be provided. This is accomplished by installing fans at mine openings or inside the mine. Mine fans are simply a means of changing the air pressure at a specified point in the mine. This is illustrated by Figures 8-3 and 8-4.

Figure 8-3 illustrates a fan set up near the portal of a tunnel driven through a mountain. The blades of the fan scoop up air from behind the fan and force it to the front of the fan. When this is done a partial vacuum or low-pressure area is created behind the fan. The air from behind the fan has been pushed to the front increasing the air pressure on the front side of the fan. As there is now a difference in pressure between two points, air will begin to flow, as long as it has a place to which it can flow. The high-pressure air in front of the fan will flow to the lower pressure areas further from the fan. The scooping action of the fan blades prevents the air from flowing back through the fan. The fan in Figure 8-3 is called a forcing fan as it is forcing high-pressure air into the mine.

Figure 8-4 illustrates an exhausting fan. This fan is creating a high-pressure area in front of the fan which is soon dissipated to the outside atmosphere. The low-pressure area behind the fan is filled by high-pressure air flowing in from the rest of the tunnel and from outside the tunnel portal.

Whether a fan is a forcing fan or an exhausting fan, the same principle of pressure differences is valid. The greater pressure difference the fan can create, the faster will be the air flow. The air, however, must have a place to which it can flow.

If the right-hand portal of Figure 8-3 were plugged, the fan would still increase the pressure in the tunnel but as the high-pressure air would have nowhere to go, it would simply stay there. The higher pressure in the tunnel would be maintained by the fan blades. If the fan were to stop the high-pressure air in the mine would flow back out through the stationary fan blades until the pressure in the mine was the same as the pressure outside.

AIR DISTRIBUTION

As air flows through a mine it always takes the easiest path, that is, the path which offers the least effective resistance.

The resistance to air flow is determined by:

- The amount of air passing.
- The roughness of the openings it is passing through (friction).
- The size of the openings.
- The length of the openings.

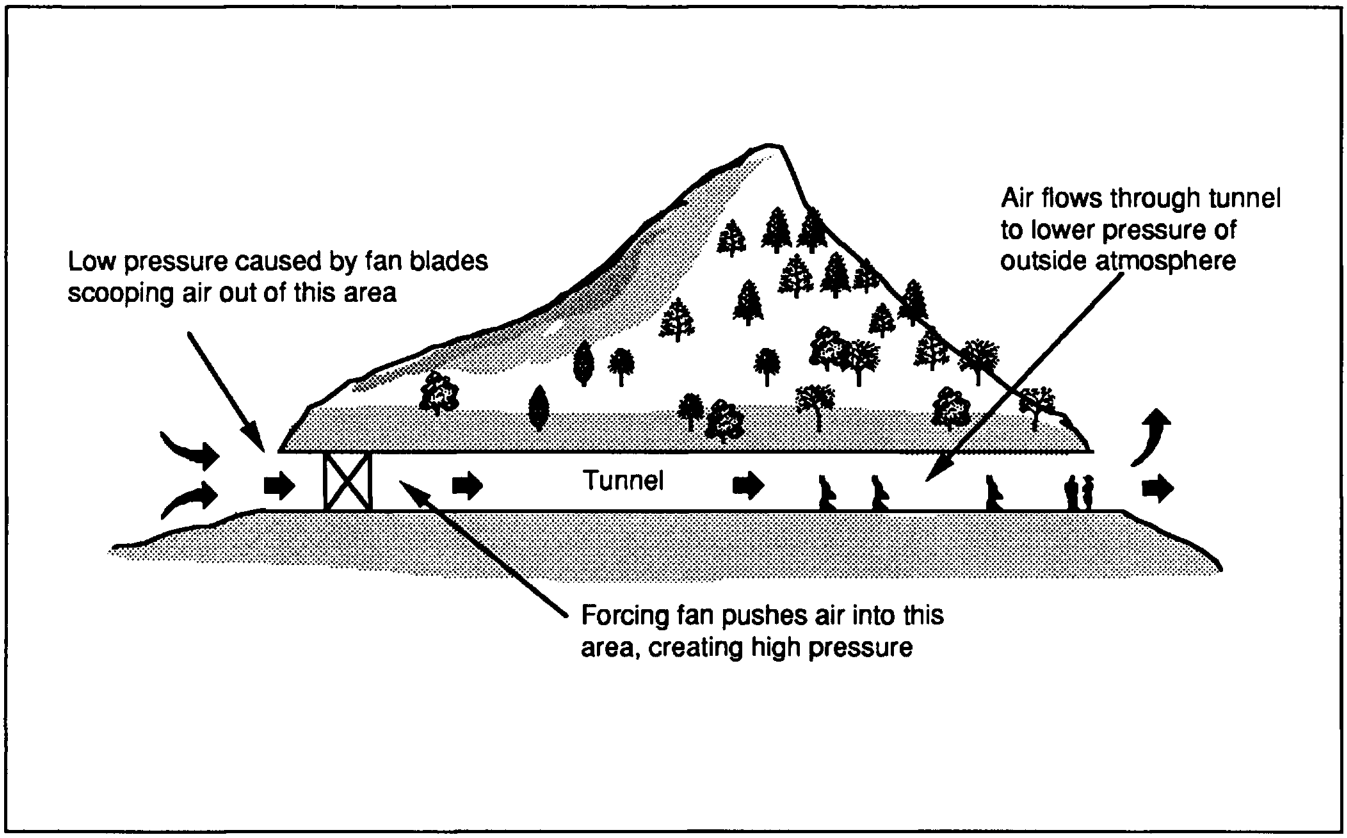


Figure 8-3. Forcing-fan mine ventilation.

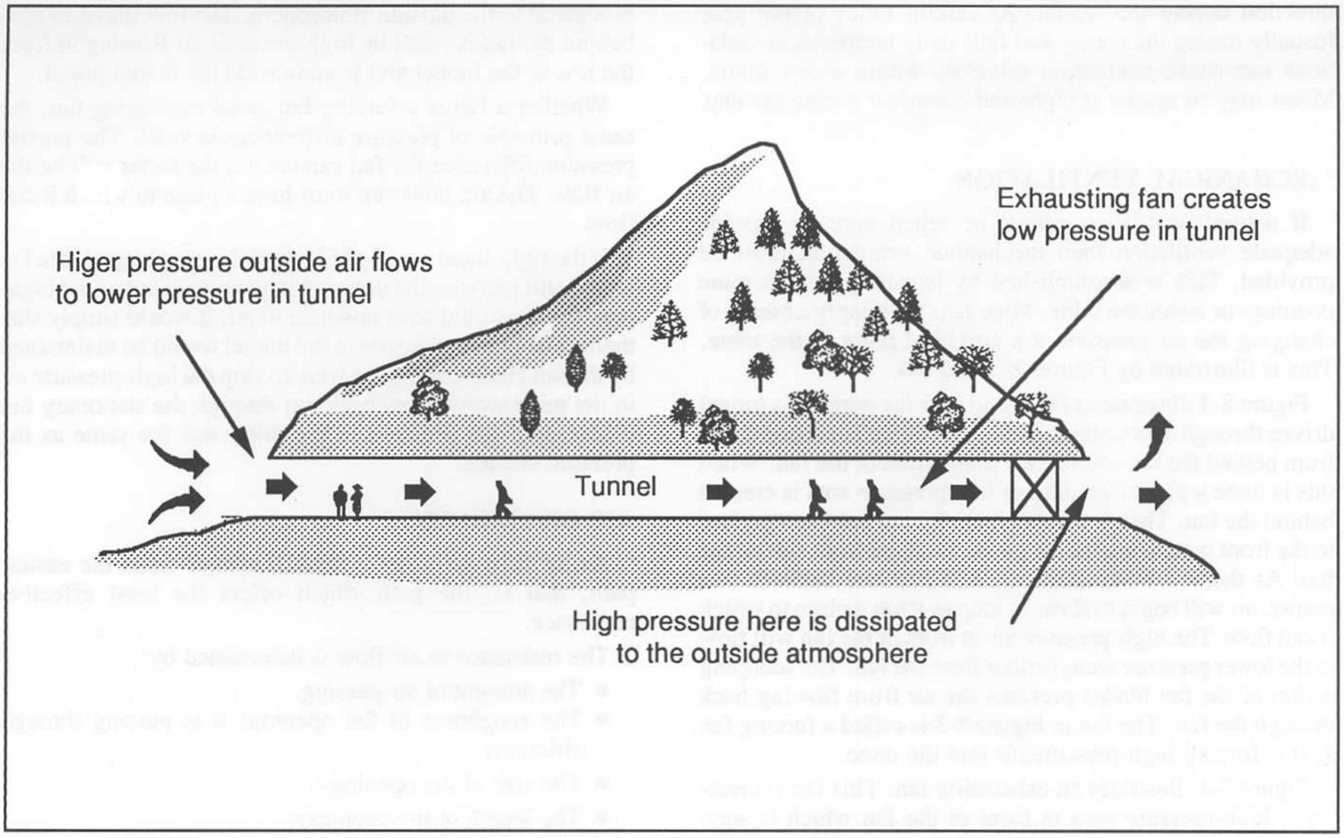


Figure 8-4. Exhaust-fan mine ventilation.

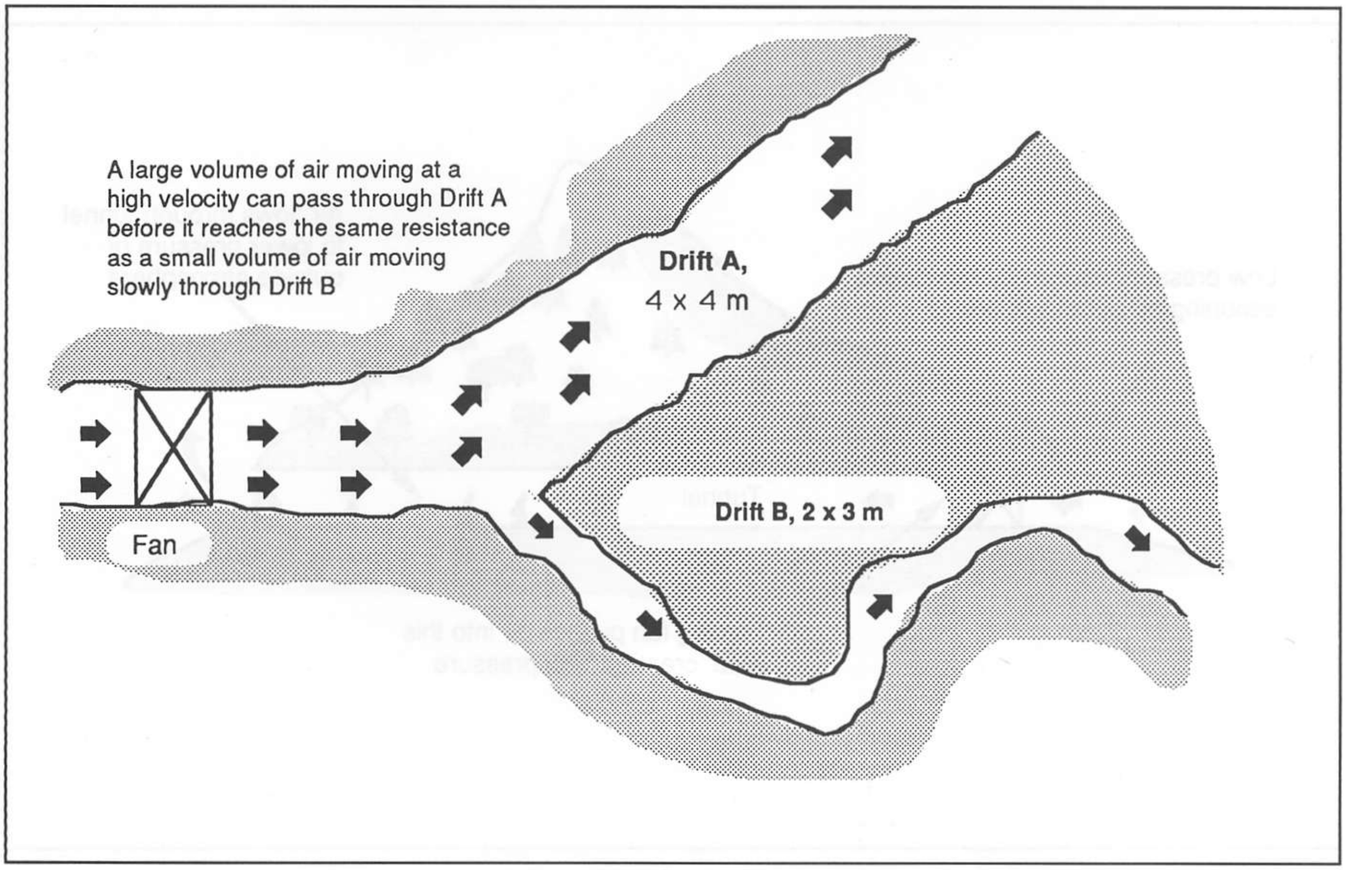


Figure 8-5. How "mine resistance" affects the flow of air through underground openings.

Air will pass much more easily through a large diameter, smooth-walled tunnel than it will through a small diameter, heavily timbered tunnel. Restrictions in tunnels such as locomotives, trackless mining equipment, conveyors, ventilation regulators, etc., will add to the effective resistance of a mine opening and make it more difficult for air to pass.

SPLITS

If air flowing through a mine working comes to a place where it branches into two or more openings, the air will split and some will flow through each opening. The amount which flows in each direction will be determined by the effective resistance in each opening.

If one of the openings is smaller or longer, or has a rougher surface, then it will offer more resistance and a smaller amount of air will pass through it. Each of the openings will have the same total resistance. However, the larger, smoother, shorter opening will allow more air to pass before it builds up the same resistance as the smaller tunnel. Figure 8-5 illustrates this principle.

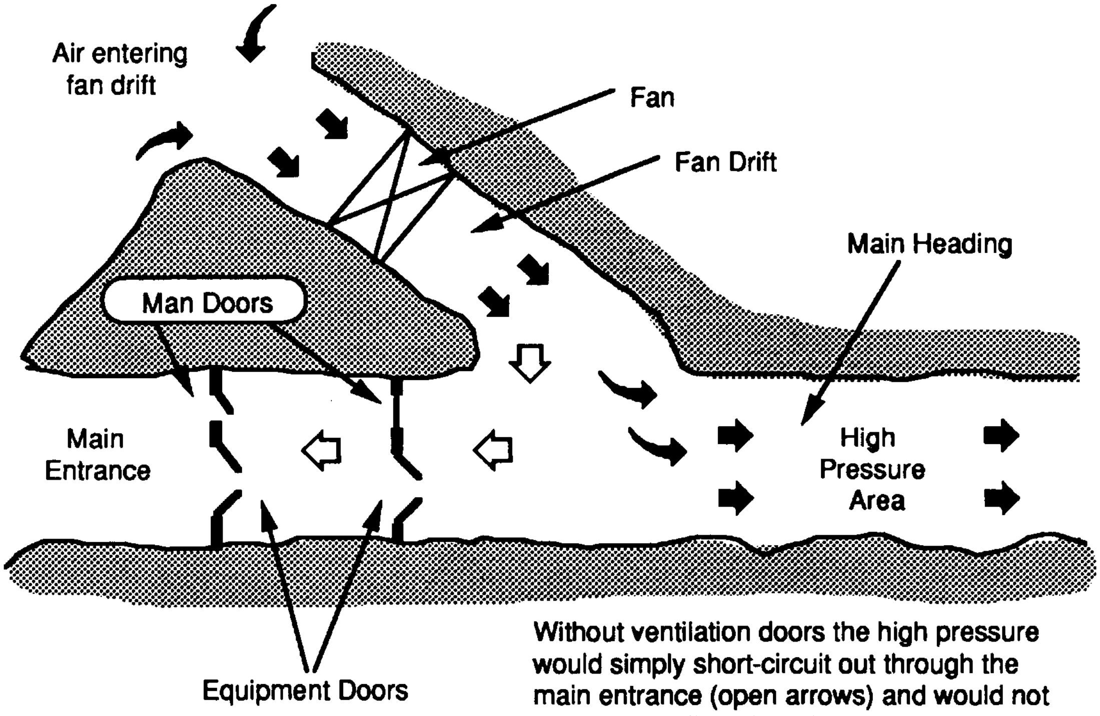
When a split occurs in an airway, more air will flow in large smoothly lined openings than in small rough-walled openings. Air will not flow into dead-end drifts as it has nowhere to go.

Quite often air will not flow to the places it is needed in the quantities that are required. In such cases it must be routed to where it is needed. The most common methods of routing air to where it is required are:

- Ventilation stoppings and doors.
- Ventilation regulators.
- Auxiliary fans.
- Auxiliary fans with ventilation ducting.
- Line brattices.

Ventilation stoppings and doors is used to stop air from going where it is not wanted and forcing it to go where it is needed. The use of stoppings and doors is illustrated in Figures 8-6 and 8-7.

When main fans are installed in a mine they are offset from the main mine entrance. When air is forced into the main opening the high pressure produced would simply short-circuit back out of the mine entrance if ventilation doors were not provided (Figure 8-6). Because of the high pressure produced by the fans, it would be difficult to open or close these doors if just one door was installed. For this reason two doors are used so that a neutral pressure area is created between them. To travel through such an air lock only one



Without ventilation doors the high pressure would simply short-circuit out through the main entrance (open arrows) and would not properly ventilate the mine. Double doors make it possible to open doors against the high pressure produced by the fan.

Figure 8-6. The use of ventilation doors to control air flow.

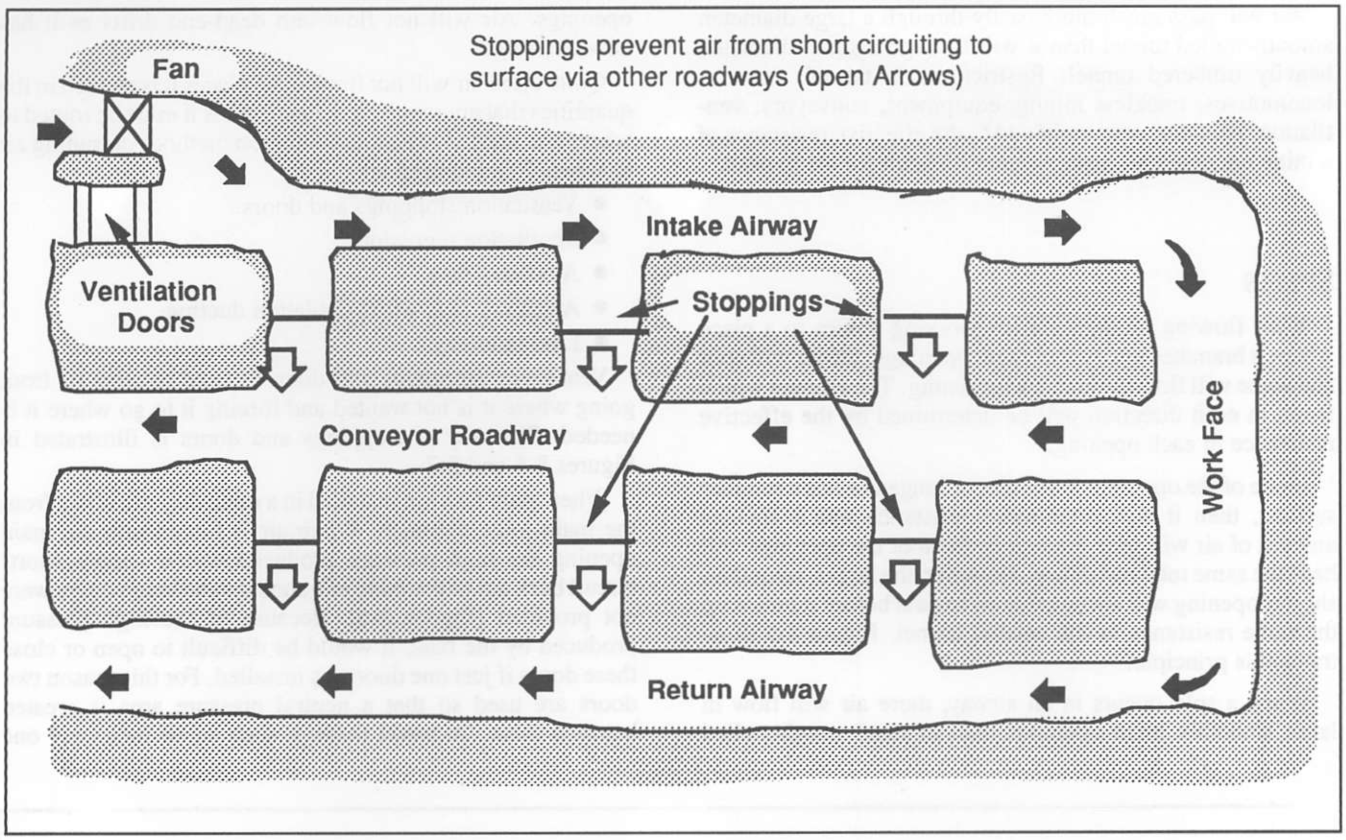


Figure 8-7. The use of ventilation stoppings to control air flow.

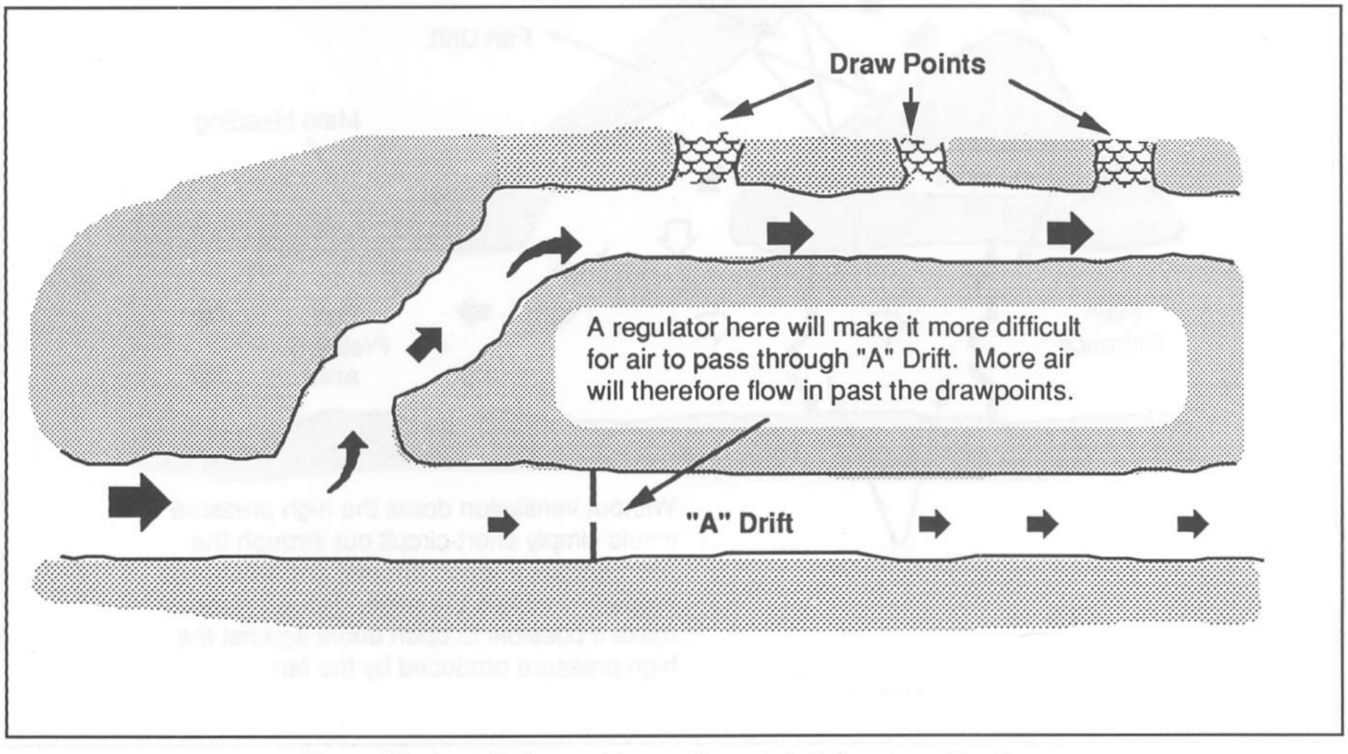


Figure 8-8. A ventilation regulator used to control air flow to a subheading.

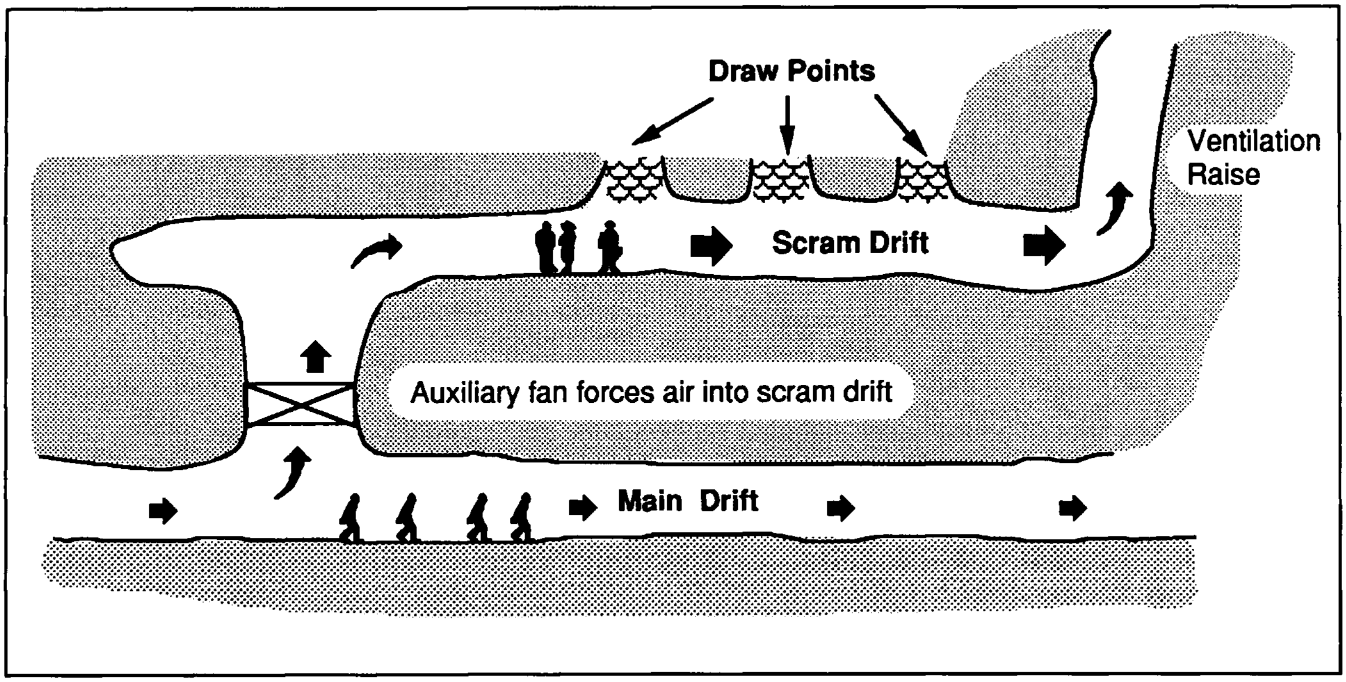


Figure 8-9. An auxiliary fan ventilating a sublevel or scram drift.

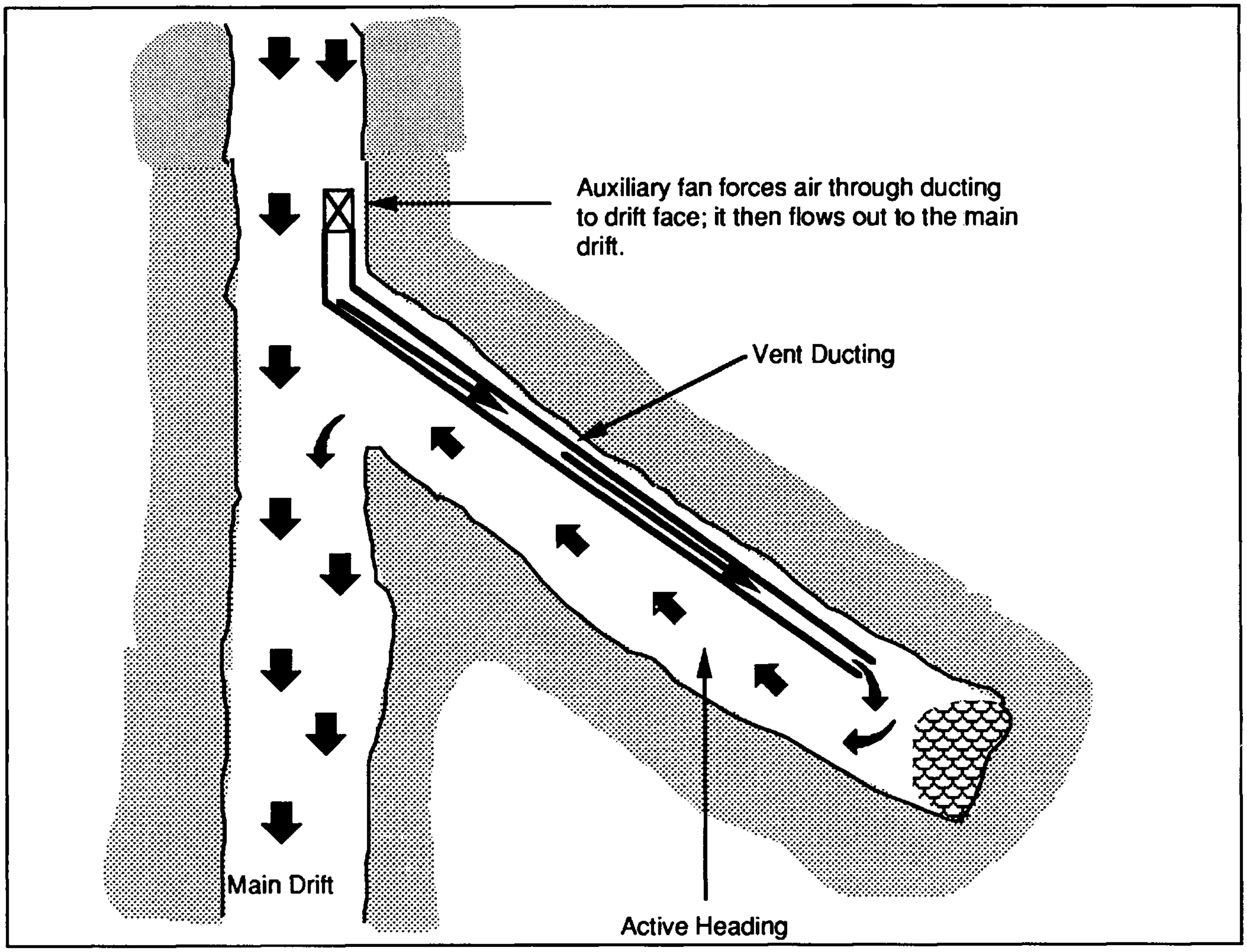


Figure 8-10. An auxiliary fan ventilating a dead-end heading.

door is opened at a time. Air locks usually have two sets of doors, large ones for equipment and small doors for miners, so that miners need not open the large doors to pass through.

It is important that doors be kept in their proper positions so as not to interrupt or change ventilation in the mine.

Stoppings are used when access is not required; doors are used when access is required. There are many ways in which stoppings and doors are used to route air through mines but all they do is isolate high-pressure areas from low-pressure areas where air is not required (Figure 8-7).

Fire doors are used to control air flows in the event of mine fires and at such times they serve the same purpose as stoppings or ventilation doors. Fire doors are often built at strategic locations in mines, such as at shaft stations. In the event of fire they are closed so as to isolate sections of the mine. If installed, fire doors must be kept clear of obstructions and in working condition at all times.

Ventilation regulators are used to reduce the amount of air passing through certain airways and thus increase the amount through other airways. A regulator increases the amount of resistance in an airway and thus makes it more difficult for large amounts of air to pass. A regulator is simply a stopping with an adjustable-sized opening in it. A partially opened door has the same effect as a regulator and is often used for this purpose. The use of regulators is illustrated by Figure 8-8.

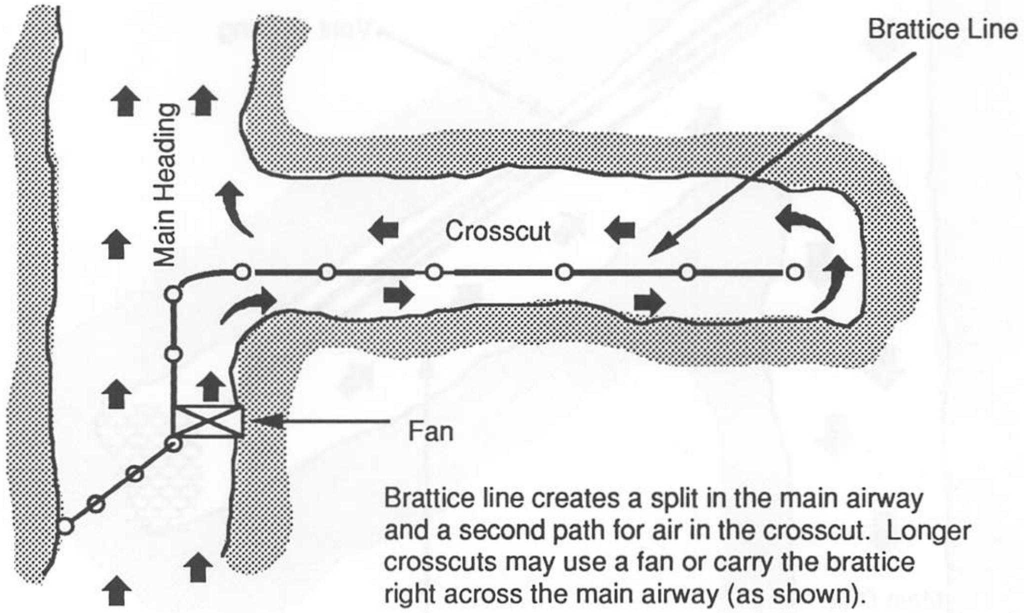
As regulators are used to control the amount of air flowing to the various parts of a mine it is important that their settings are not changed by unauthorized personnel, otherwise unwanted ventilation changes will occur and some areas may not receive the required amounts of air.

Auxiliary fans are often set in places where it is necessary to increase air pressure to force air through workings that are difficult to ventilate in other ways. Dusty places or places where blasting gases may accumulate often require auxiliary fans to provide proper ventilation. The scram drift illustrated in Figure 8-9 is a good example. The auxiliary fan in this figure forces relatively large quantities of fresh air through the scram drift where it carries dust and blasting smoke out of the scram drift to the ventilation exhaust system. If a fire were to occur in this mine and the main drift were to become filled with dangerous gases, what action should a crew in the scram drift take?

When dead-end working places require ventilation it is often necessary to use auxiliary fans in conjunction with ventilation ducting. Air will not flow into a working place unless it has a place to go. The ducting channels the air to the end of the heading and it can then flow out through the main part of the heading. The fan forcing air through a duct must be located in such a way that air coming out of the heading does not re-enter the ducting and go back into the working place. Figure 8-10 illustrates the use of ducting to ventilate an active drift heading.

As in the case of the scram drift, if the main drift was to be contaminated by fumes and smoke from a fire and the drift crew had to stay in the heading, the fan would draw the gases into the drift unless it was shut down.

Coal miners often use lines of brattice cloth to serve the same purpose as ventilation ducting. Brattice cloth is a tightly woven, heavy, fire-resistant cloth which is hung from roof to floor to create a second air path in a dead-end heading.



Brattice line creates a split in the main airway and a second path for air in the crosscut. Longer crosscuts may use a fan or carry the brattice right across the main airway (as shown).

Figure 8-11. A brattice line used to direct air flow into a dead-end heading.

Figure 8-11 illustrates the use of brattice cloth for auxiliary ventilation. Auxiliary fans may be used in conjunction with brattice cloth, but more often the brattice just creates an artificial second path in the airway. If the dead end is short the brattice need not go right across the main airway and only a part of the air in the main airway will be diverted. For longer dead ends the brattice is carried right across the main airway and all of the air is circulated into the dead end.

This section has explained some of the principles of air movement in mines and some of the methods used to ventilate mine workings. Underground workmen should never change mine ventilation by disturbing regulators, altering door positions or shutting off fans, unless instructed to do so, as fellow workers could be seriously affected.

Keep in mind that air will always travel from a high-pressure area to an area of lower pressure and warm, lighter air will tend to rise to higher places.

INSTRUMENTS USED IN VENTILATION WORK

MINE WATER GAUGE

A mine water gauge is a U-shaped glass tube having a 0.25-inch (0.6-centimetre) bore and mounted on a suitable base with an adjustable scale (Figure 8-12). Water is put in the bend of the tube; the difference of water level in the two arms of the gauge indicates the difference in pressure exerted on them. Both ends of the tube are open and one arm is extended and bent at right angles so that it can be inserted into a hole in the wall or door separating the intake and return airway. The pressure on the intake is always greater than on the return side of the mine. This causes the water level to sink in the arm of the tube on the intake side and rise a corresponding amount on the side open to the return. The difference in the two levels is read on a scale in inches; each inch of water gauge reading corresponds to a pressure of 0.25 kilopascal [5.2 pounds per square foot (psf)]. A water gauge reading of 2.5 inches would show a ventilating pressure of 0.6 kilopascal (13 psf).

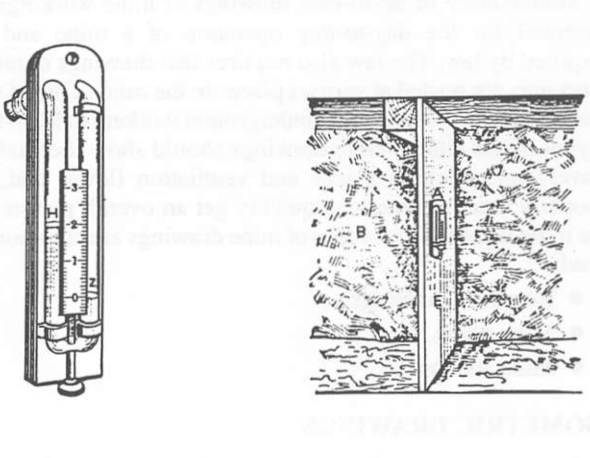


Figure 8-12. (A) Mine water gauge. (B) Water gauge mounted on a stopping.

A cube 12 inches on each side, filled with water, weighs 62.5 pounds (28 kilograms). It is evident that a depth of 1 inch will have a weight of 62.5 ÷ 12 = 5.2 pounds. Thus 1 inch of water distributed over a square foot of area corresponds to a pressure of 5.2 pounds per square foot.

THE MINE RESISTANCE

The resistance of the mine is a definite quantity and bears no relation to the capacity or qualities of the ventilating appliances or methods. The water gauge measures this resistance. The water gauge reading is a function of the mine and a measure of the relative ability of the mine to pass air through its workings effectively. The water gauge reading in the majority of mines varies from 1 inch to 3 inches (2.5 to 7.5 centimetres). Few have a larger resistance. A mine with large ventilation airways and well-distributed ventilation should have a water gauge reading, or resistance, not exceeding 1 inch (2.5 centimetres) for each 100 000 cubic feet (2800 cubic metres) of air circulating through it. A mine having a higher reading than this either has airways that are too small or is not receiving a properly regulated air flow.

ANEMOMETER

An anemometer (Plate 8-1) is used to determine air flow for ventilation purposes. It consists of a rotating vane mounted within a steel ring; the blades of the vane are inclined to the plane of rotation. The air current striking the blades rotates the vane, the number of revolutions is recorded on the face of a dial by means of a series of gears. The instrument is calibrated so that each revolution of the vane corresponds to 1 lineal foot of air travel. It measures the velocity of the air current in feet per minute.

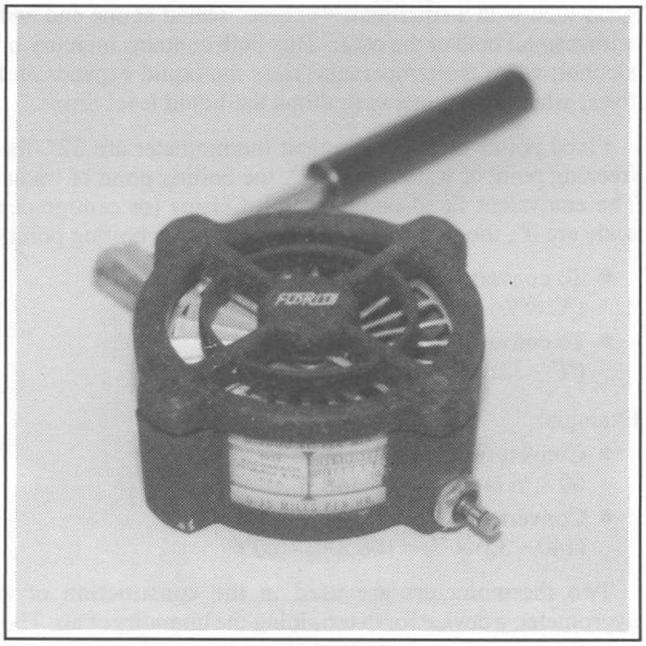


Plate 8-1. An anemometer of the type used in underground ventilation work.

VELOMETER

The design of a velometer is based on the pitot tube principle. Pressure exerted on a vane travelling in a circular tunnel causes a pointer to indicate the velocity of air moving through mine workings on a scale, either in Imperial or metric units (*see* Plate 8-2).

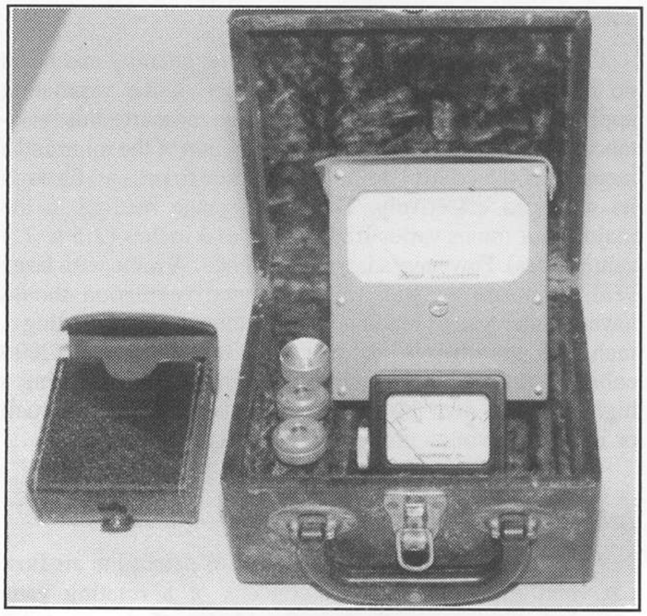


Plate 8-2. A velometer for measuring the rate of flow of air in mine workings.

THERMOMETER

Temperature is measured by thermometers on either the Fahrenheit or Celsius scale. Thermometers consist of a thick glass tube with a small uniform bore, sealed at one end and with a small bulb at the other. This bulb contains mercury or alcohol; when the temperature rises the liquid expands and rises, when the temperature drops the liquid level drops.

Fixed points on the Fahrenheit thermometer are 32°, the freezing point of water, and 212°, the boiling point of water. The equivalent fixed points on the Celsius (or centigrade) scale are 0°, the freezing point, and 100°, the boiling point.

- To convert Celsius to Fahrenheit: $(°C \times 9/5) + 32 = °F$.
- To convert Fahrenheit to Celsius: $(°F - 32) \times 5/9 = °C$.

Example:

- Convert 60°C to Fahrenheit
  $60 \times 9/5 = 108 + 32 = 140°F$
- Convert 140°F to Celsius
  $(140 - 32) \times 5/9 = 108 \times 5/9 = 60°C$

Two thermometers are used in the construction of a hygrometer, a device for determining the humidity of air. The thermometers are mounted side by side on a frame and the bulb of one is covered with muslin kept moistened with water. Evaporation from the moistened bulb lowers the temperature so that this thermometer reads lower than the dry bulb. The thermometers should be mounted so as to permit the free circulation of air around both bulbs. Usually the device is constructed so that it can be freely swung in the air being monitored, in order that the thermometers will reach constant readings. The two readings are recorded and the relative humidity of the air is determined by reference to a chart or special sliderule.

BAROMETER

A barometer is an instrument used to measure the pressure of the atmosphere. The most reliable instrument for this purpose is a mercurial barometer. This consists of a glass tube closed at one end and open at the other. This tube is first filled with mercury and then inverted with its open end immersed in a basin or vessel of mercury. The surface of the liquid in the basin is exposed to the pressure of the atmosphere, the column of mercury in the tube sinks to a level such that the weight of the mercury column is supported by the atmospheric pressure acting on the surface of the mercury in the basin, there being a vacuum at the top of the tube. Since each cubic inch of mercury weighs 0.49 pound and the height of the mercury column supported by atmospheric pressure at sea level is 30 inches (76 centimetres), the atmospheric pressure at sea level is $30 \times 0.49 = 14.7$ psi (101.3 kPa).

A rapid fall in the barometer indicates a decrease in the atmospheric pressure which in turn decreases the mine ventilating pressure. This would allow the gases in gobs and abandoned workings to expand and flow into the active workings, creating a dangerous condition.

The barometer provides an indication of changing elevation; pressure decreases by approximately 1 centimetre of mercury for each 110 metres (360 feet) of ascent.

MINE DRAWINGS

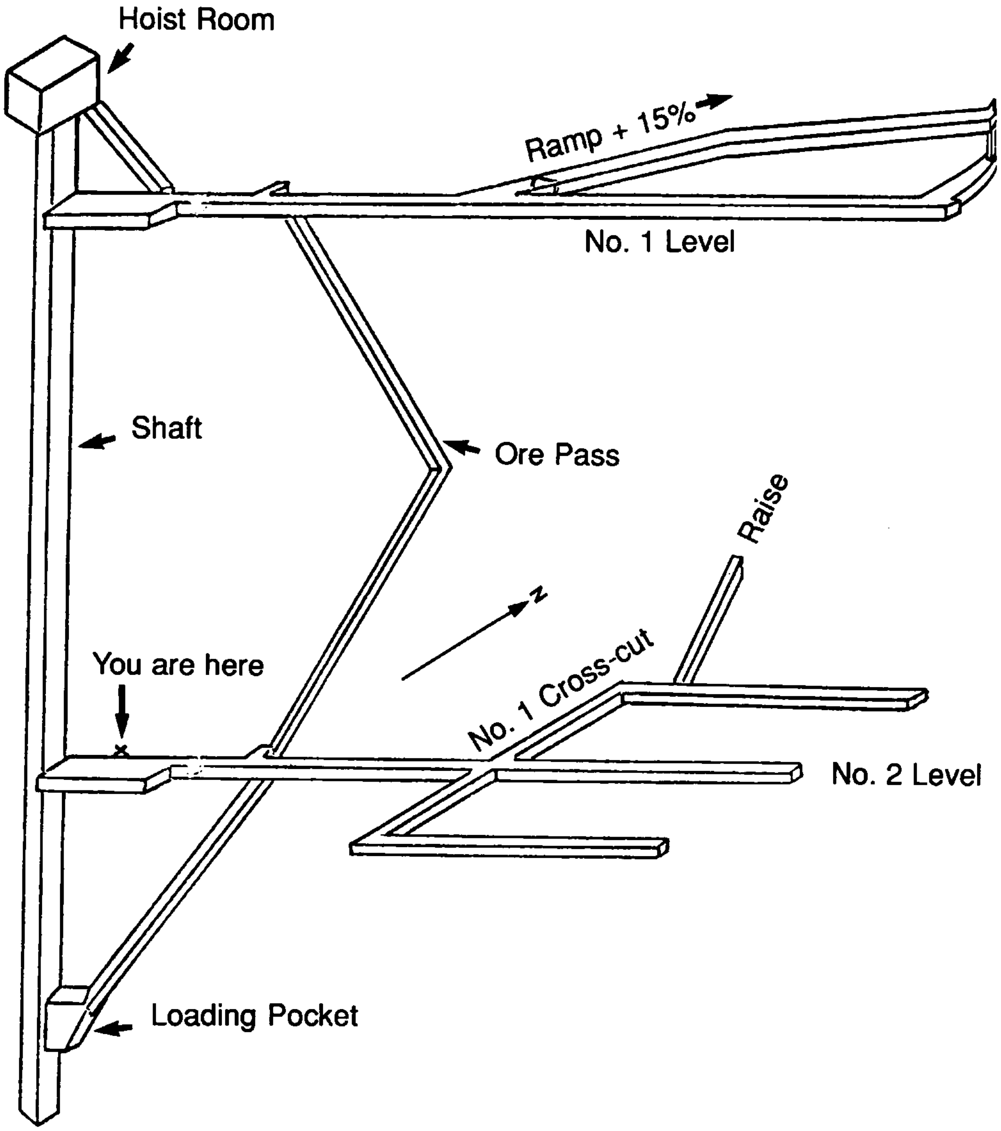
The discussion of mine ventilation made use of several drawings showing air circulating through mine workings. These drawings are simplified mine plans and sections.

Maintenance of up-to-date drawings of mine workings is essential for the day-to-day operation of a mine and is required by law. The law also requires that drawings of mine workings are posted at various places in the mine. One of the reasons for this is to enable underground workers to learn the layout of the mine. These drawings should show the shafts, travelways, working places and ventilation flows, and, if properly read, a miner can quickly get an overall picture of the mine layout. Three types of mine drawings are commonly used:

- Isometric drawings.
- Mine plans.
- Mine sections.

ISOMETRIC DRAWINGS

An isometric drawing is simply a three-dimensional picture of the mine workings. It shows what the workings would look like if all the rock surrounding the mine openings was



ISOMETRIC DRAWING

Figure 8-13. A simplified isometric drawing of an underground mine.

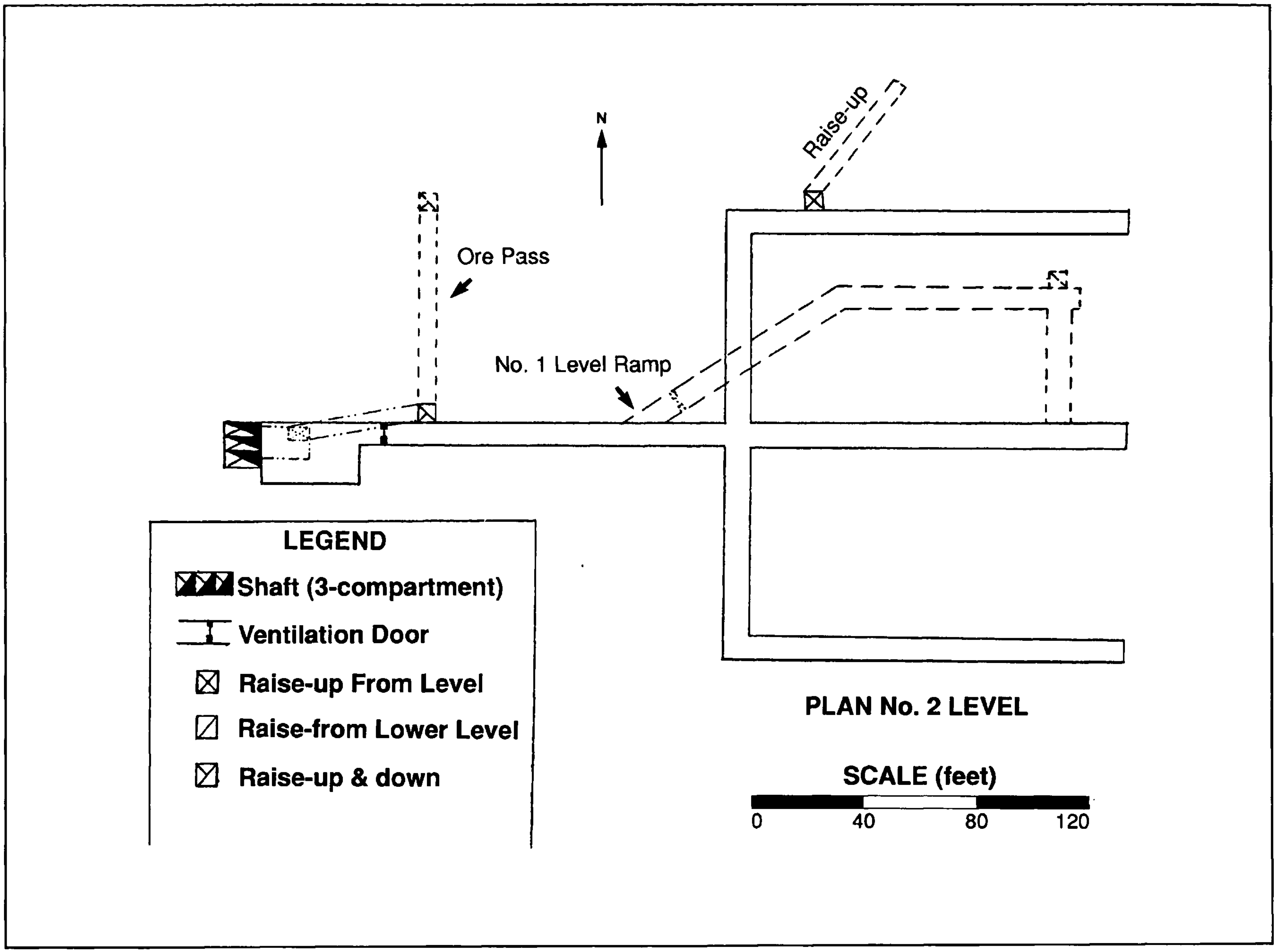


Figure 8-14. A plan of No. 2 level in the mine illustrated in Figure 8-13.

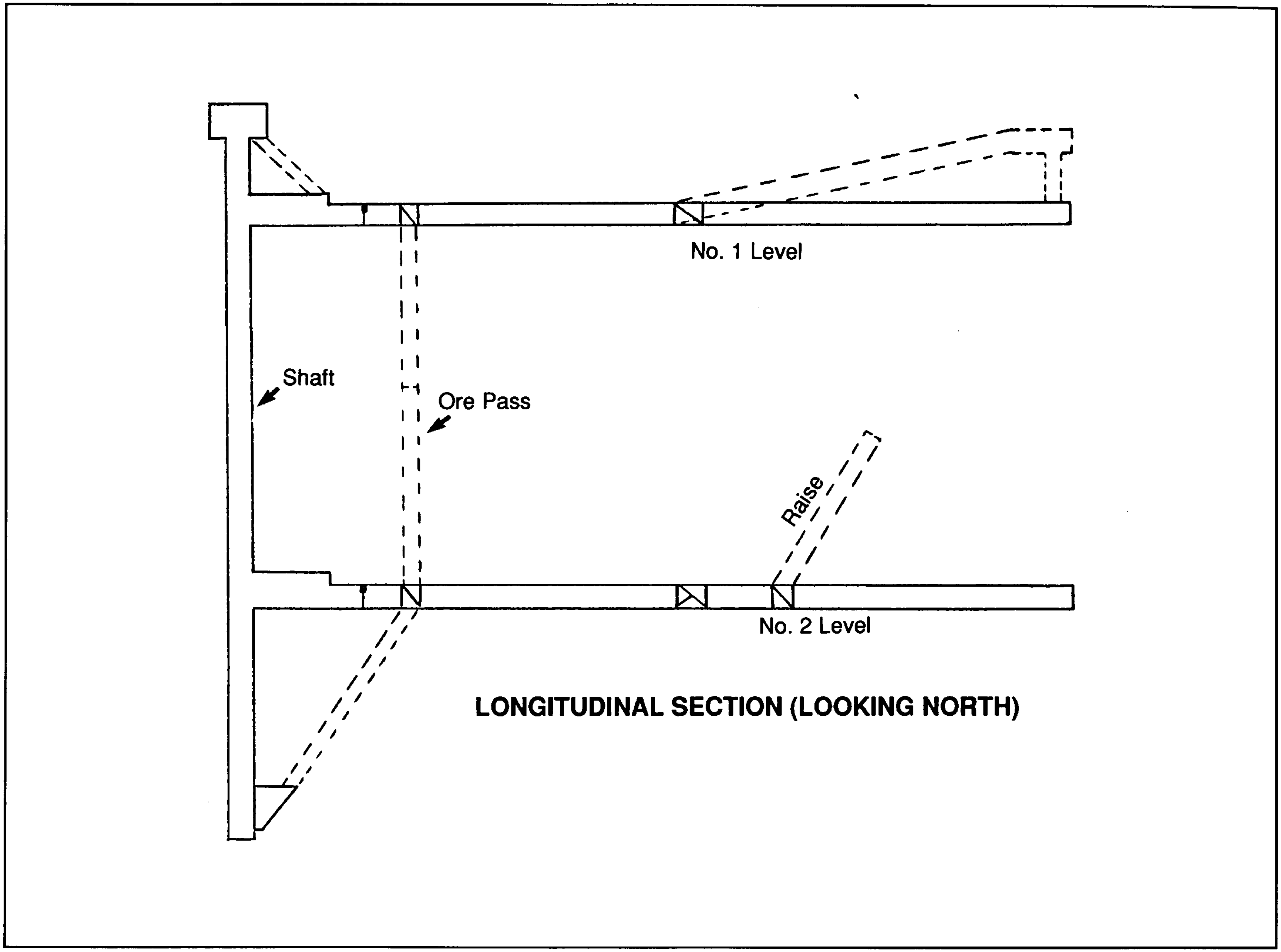


Figure 8-15. A longitudinal section through the mine illustrated in Figure 8-13.

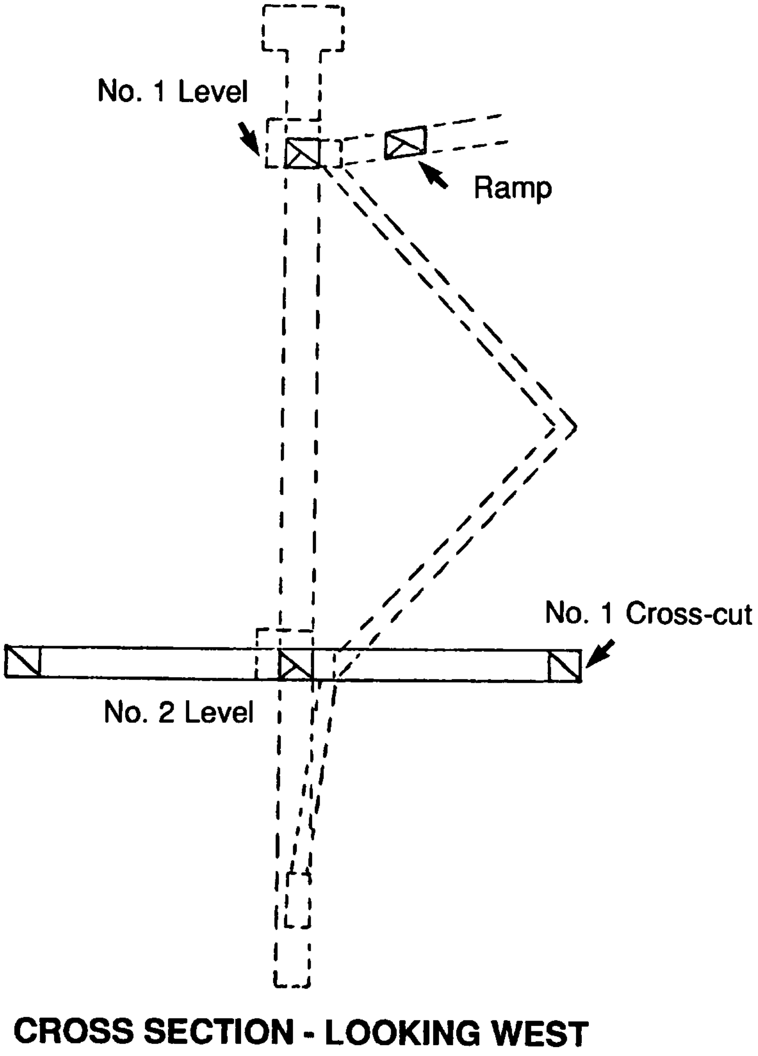


Figure 8-16. A cross-section through the mine illustrated in Figure 8-13.

transparent. With the advent of trackless mining methods using inclined and spiral ramps, normal mine drawings become quite difficult to read unless you are familiar with the mine layout; isometric drawings provide a quick overview. Figure 8-13 is an example of a simple isometric drawing and needs no further explanation. If the mine workings are more complex, it may be necessary to exaggerate the vertical scale of the drawing so that different levels do not appear to overlap.

If isometric drawings are posted underground, a notation such as "YOU ARE HERE" and an arrow, will show the location of the posting relative to all mine workings. The drawing used as an example in Figure 8-13 would be posted at the shaft station on No. 2 level. A person at the shaft station would have no difficulty seeing how to get to any other location in the mine.

MINE PLANS

City or highway road maps and house plans are drawings of things as they would appear to a viewer suspended directly above them. Mine plans are no different. The plan of a level in a mine shows what it would look like if all the rocks were removed and the openings viewed from above.

Mine plans are drawn at various scales and the scale will always be noted on the drawing. Before the introduction of metric units, a scale of 1 inch equals 40 feet was very common; meaning that 1 inch on the drawing represents an actual distance of 40 feet in the mine. The number of inches between two points on the plan, multiplied by 40, gives the distance between the two points in the mine, measured in feet. If two points on the plan are 10 inches apart, they are 400 feet apart in the mine ($10 \times 40 = 400$). The equivalent metric scale is 1 centimetre equals 500 centimetres (5 metres), usually expressed as 1:500; a distance of 5 centimetres on the plan represents 2500 centimetres (or 25 metres) in the mine ($5 \times 500 = 2500$).

It is customary to draw sepatate plans for each level in the mine. The level each plan refers to is drawn in solid lines and the levels immediately above and below are often shown by dashed lines. Different styles of broken lines may be used to indicate different levels. Symbols are also used to indicate such things as fans, ventilation doors, shafts, raises, ore passes and so on. The symbols may vary from mine to mine and a legend will be provided to explain what they mean.

The example in Figure 8-14 is a plan of No. 2 level in the isometric drawing shown in Figure 8-13. The ore pass and the workings on No. 1 level are indicated by broken lines, except where they directly overlap the central drift on No. 2 level and cannot be shown separately. Some common symbols are used in this figure. All mine plans also show which direction is north, either with a north arrow, as in the figure, or with grid lines in a north-south and east-west direction.

Plans of working mines are usually much more extensive than the simple example in the figure, but the same principles apply. Keep in mind that the plan is a representation of what the workings would look like if viewed from above. Study the legend to determine which raises lead up to the level above and which down to the level below.

MINE SECTIONS

Mines with large vertical dimensions, especially metal mines, require the use of "sections" to obtain a good representation of the mine layout. A section can be thought of as a vertical plan. Most metal mines have one very long dimension and one short dimension, resulting in the use of two kinds of sections, "longitudinal sections" along the long dimension and "cross-sections" across the shorter dimension, the width of the orebody.

LONGITUDINAL SECTIONS

Referring again to the isometric drawing in Figure 8-13, imagine a vertical plane passing through the mine and all the workings cut by the plane represented on a drawing. The drawing would be a vertical section. If the vertical plane passes through the mine in such a way that it intersects the shaft and is parallel to the main drifts on No. 1 and No. 2 levels, it is a longitudinal section. In order to orient the sectional drawing properly, the direction the viewer is looking must also be noted; Figure 8-15 is a longitudinal section of the mine, looking north. You are looking at a vertical slice through the mine, as seen from the south looking northward. The solid lines represent the workings cut by the section; the dashed lines are workings behind the slice.

CROSS-SECTIONS

A cross-section is the same as a longitudinal section except that the vertical slice is taken across the short dimension of the mine. The example in Figure 8-16 is a cross-section of the mine in the isometric drawing, looking west, toward the shaft. The plane of the section is along the No. 1 crosscut and this is the only opening shown in solid lines; the shaft and the ore pass are behind the section and shown in broken lines. Most cross-sections will show relatively few workings and have only limited usefulness in illustrating the mine layout. They are used primarily by engineers and geologists for mine planning.

SUMMARY

Summing up, mine drawings are a way of representing mine workings on paper. Isometric drawings are the easiest to understand but, with a little practice and thought, plans and sections can be interpreted easily by all underground workers. The ability to read mine drawings makes it relatively simple to visualize the mine layout and this becomes vitally important in an emergency, when you must quickly decide the best escape route from the mine. All underground workers should make a point of studying mine drawings for their mine. If you do not understand the drawings that are posted, ask your supervisor to explain them to you.

DO NOT WAIT FOR AN EMERGENCY TO LEARN THE MINE LAYOUT, VENTILATION FLOWS, ESCAPE ROUTES AND THE LOCATION OF REFUGE STATIONS. YOU NEED TO KNOW INSTINCTIVELY WHAT TO DO AND WHERE TO GO TO REACH SAFETY IN THE SHORTEST POSSIBLE TIME.

UNDERGROUND MINE FIRES – CONTROL AND SUPPRESSION

All the principles covered in Chapter 6 also apply to fighting fires underground; it is recommended that students reread this chapter. Underground rescue workers must have a basic knowledge of the chemistry of fire, as summarized by the Fire Triangle and Fire Tetrahedron, and understand how fire behaves. Underground fires are classified in the same way as fires on surface and progress through the same four phases. Firefighting techniques are similar, but adapted to take into account the unique conditions present underground.

Methods of controlling and extinguishing mine fires are:

- Fighting by direct attack.
- Sealing the fire area to exclude oxygen.
- Flooding the fire area or the entire mine with water.
- Flushing the fire area with silt or other solids.
- Flushing the fire area with high-density foam.
- Smothering the fire with an inert gas such as carbon dioxide.
- Using incombustible barriers to prevent the spread of fire.
- Unsealing the fire area to recover bodies, to remove smouldering material, or to reventilate it.

FIGHTING FIRES BY DIRECT ATTACK

Many mine fires can be put out at an early stage by direct attack with water, chemicals, rock dust or sand. Failure to extinguish fires by direct attack is usually due to late discovery, lack of water or of a means for applying it promptly, lack of fire extinguishers or other facilities, and improper procedure in the initial or subsequent attack.

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

HIGH-EXPANSION FOAM

High-expansion foam is recommended for confined areas such as basements, buildings, mine shafts, sewers and other places generally inaccessible to the firefighter.

What Is It?

High-expansion foam liquid concentrate is a careful blend of premium-grade surface-active agents and a synthetic detergent foaming agent. This concentrate is mixed with water, then expanded with air to form high-expansion foam. When used in combination with a National High-expansion Foam Generator, it makes a superior foam with an average expansion ratio of 500:1, but can be used with generators producing foams with expansion ratios from 100:1 to 1000:1. The foam liquid produces a foam with a smooth texture and uniform bubble size which flows easily around and over obstructions. Its tough adhesiveness provides a foam of superior stability. This foam liquid has a high expansion capability and good stability when used with either fresh or sea water.

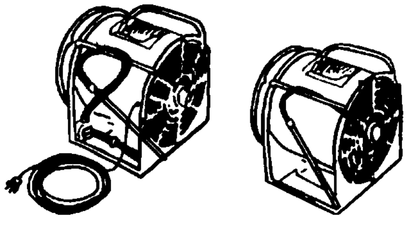
In addition to being a superior foaming agent, it also has an emulsifying ability for cleaning up oil spills and a wetting ability to increase the penetrating effect of water on deep-seated Class A fires. Its all-purpose use eliminates the need for stocking emulsifying and wetting agents.

How It Works

High-expansion foam controls fires by cooling, smothering and reducing the oxygen content by steam dilution. A fast-draining foam, such as produced by many detergents, will lose most of its water and provide only a filmy network of bubbles. High-expansion foam liquid is formulated to retard drainage and provide stability.

How It Is Made

High-expansion foam is made by introducing a small amount (1.5 per cent) of foam liquid into a foam generator (Figure 8-17) where water and an immense quantity of air (up to 1000 times the quantity of water and liquid) are mixed in a turbulent state. The result is a tremendous blanket of foam. One 19-litre (5 US gallons) can of National High-expansion Foam Liquid can produce about 1.5 million litres (one-third of a million gallons) of foam. This would be enough to cover a football field to a depth of 30 centimetres (12 inches).



	National Foam EP-30 Electric	**National Foam WP-25 Water-powered**
Capacity	3000 cu. ft./min.	2500 cu. ft./min.
Alternate Use	Smoke ejector	Smoke ejector
Weight	78 lbs.	56 lbs.
Foam Expansion	To 1000 to 1	To 1000 to 1
Powered By	115V 50 Cycle 115V DC 220V 60 Cycle 200V 50 Cycle	Water Powered No Electricity Required
Option	Remote Proportioning	Remote Proportioning
Connection	1½″ Female Swivel	1½″ Female Swivel

Figure 8-17. Foam-generating equipment. MSA foam cart, National Foam EP-30 electric-powered foam generator and WP-25 water-powered foam generator.

Foam Generators: Foam – Where and When You Need It – Fast!

The Rover Foam Cart (Plate 8-3) is the ideal mobile firefighting unit for protection of oil storage and loading areas, workshops and all high-risk areas where flammable liquids are used and stored. Even when charged with 100 litres (28 US gallons) of foam concentrate, the Rover is easily moved and operated by one person. Always ready for action, it operates from a standpipe or other pressurized water source and provides up to 15 minutes of application, depending on the choice of foam concentration, eductor and nozzle flow.

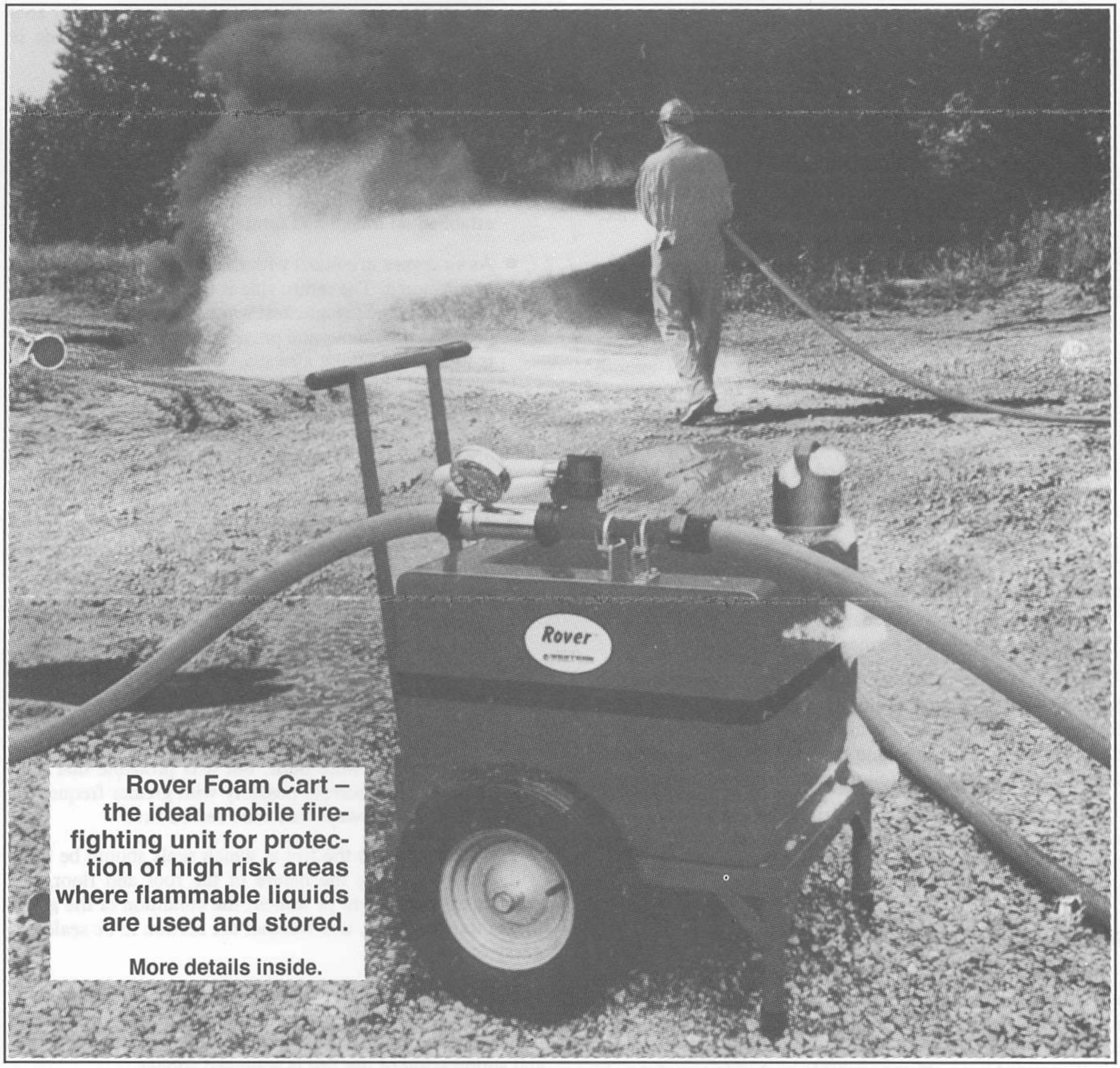


Plate 8-3. The Rover Foam Cart, a typical mobile firefighting unit.

USE OF ROCK DUST OR SAND

Fine limestone or shale dust for rock-dusting bituminous coal mines can be used successfully in fighting incipient fires as well as larger fires under some conditions. Rock dust not only serves to extinguish flame directly, but excludes air from burning material thereby smothering the fire. Rock dust can also be used to cool heated material loaded in cars and is preferable to water for such uses, as no steam is formed.

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

SUMMARY OF DIRECT ATTACK PROCEDURES

In summary, if a fire is found underground, prompt action must be taken as follows:

(1) If the fire is large and can obviously not be controlled quickly, sound the alarm by established means, warn men in the immediate area and begin evacuation procedures.

(2) If it appears that the fire can be quickly contained, take what firefighting action is necessary, using equipment that is readily available. Use the smothering approach on Class B and Class C fires. Water and Class A extinguishers can be used on Class A fires. Approach the fire from the ventilation intake side (if possible) and keep your own safety foremost in mind. Be careful of confined spaces when using the smothering-type fire extinguishers and never touch fire-damaged electrical equipment.

(3) If definite progress is not being made after a few minutes, or it becomes apparent the fire cannot be contained, proceed as in (1) above.

(4) Always be aware of the deadly gases that are being produced by even a small fire and do not expose yourself or others to these gases or to other hazards such as weakening timber.

(5) Every fire, regardless of how small, or how quickly it is put out, must be reported at once as it could have sent deadly gases into the mine air. Once put out the fire area must be monitored until reignition is impossible.

(6) The use of fire extinguishers must always be reported so that they can be recharged and readied for use if required again. A discharged fire extinguisher is of no value if another fire emergency should arise.

Any unusual occurrences in a mine should be reported at once. The smell of smoke, clouds of dust, air blasts, sudden changes in ventilation, or the interruption of power supplies, could all mean that something unusual has happened. Your life and the lives of your fellow workers may be in danger.

If any of these circumstances arises, be it a visible fire or an indication that something unusual has happened, do not panic but act promptly. Keep cool and use your head.

SEALING UNDERGROUND MINE FIRES

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

There is considerable difference of opinion as to which side (intake or return) of a fire should be sealed first. Many mining men, including all those who have provided material for this manual, prefer to seal the intake and return airways simultaneously, especially if the fire is in a section of a mine where explosive gas is being liberated. If this is not feasible because of the distance between openings, or for other reasons, it is advisable to seal the intake airways first. The reasons for this are:

- Unless the fire is being fanned vigorously by the ventilating current (which should not be done) it will travel mostly toward the fresh-air or intake side. In some kinds of coal the fire will travel toward fresh air quite rapidly (almost as fast as a man can walk); if the return side is sealed first the fire will burn longer, cover a larger area and be checked hardly at all until the intake side is sealed.

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

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

- All available reports on fires in gassy sections of mines (some of them extremely gassy) indicate that except where airways are sealed simultaneously, intake airways have always been sealed first. Furthermore mine engineers and safety instructors have assisted in sealing hundreds of mine fires (many of them in gassy mines) and, so far as is known, in no case have the return airways been sealed first. In all of this work no serious explosions occurred during the placing of temporary seals. In some instances explosions occurred some time after the seals were built, but it is probable that they would have occurred, possibly with greater frequency, if the return airways had been sealed first.

The distance from the fire at which seals should be built will be governed by the nature of the roof and floor, the number of openings to be sealed, the condition of the air in the section involved, and whether the section to be sealed is gassy or not.

In mines where no gas is being liberated the seals should be placed as close to the fire as possible. By sealing close to the fire less area is involved, the oxygen is depleted more rapidly and suppression of the fire is achieved sooner.

Placing stoppings to seal a fire in a gassy section of a mine is dangerous and should be done with the utmost care. The seals should be placed as far from the fire as possible, 300 metres or more (1000 feet), to allow considerable time to elapse before an explosive mixture of gas can accumulate. A prominent engineer has described sealing a fire in a gassy section of a mine as a race to have the fire deplete the available oxygen before combustible gases can accumulate to the point where they explode.

An explosion will invariably occur if gas is given off in sufficient quantities to be within the explosive range of methane (5 to 15 per cent) before the oxygen has been reduced below the level at which an explosion is possible (approximately 12 per cent). Under these conditions it is advisable to erect tight temporary seals and then withdraw all men from the mine for at least 24 hours before attempting to erect permanent seals. Furthermore, if an explosion is likely to occur after the temporary seals are built, arrangements should be made to close the last seals after all workers are out of the mine. This can be done by leaving hinged openings (doors) in one or more of the stoppings that will close automatically, and holding them open with a counterbalance. One simple method of doing this is to use a perforated bucket filled with water; the perforations should be made small enough to allow miners to reach the surface before the water drains from the bucket and the doors close to complete the temporary seals.

As a precautionary measure, when fires are being sealed off in gassy or dusty mines, it is advisable to apply a thick coating of rock dust to the ribs, roof and floor of entries, crosscuts, etc. for a metre or more outwards and, if possible, inwards from the location of temporary seals. In the event of an explosion occurring around the fire, the chance of propagating a coal-dust explosion will be reduced considerably. Although it may be possible to seal a fire in a gassy section of a mine without an explosion during or shortly after sealing operations, the safest method may be to seal the mine openings at the surface.

TEMPORARY STOPPINGS

The time element frequently enters into the construction of temporary stoppings or seals after a mine fire. The quicker they can be built the sooner air to the fire will be cut off and the flame extinguished. Therefore available materials should be used that require minimum time for construction.

Temporary stoppings or seals are generally built of brattice cloth or canvas, if available, because they can be erected quickly and can be made fairly tight (Figure 8-18). If a more substantial stopping is needed, boards covered with brattice cloth or boards with pieces of brattice cloth, stiff mud or wood fibre packed around the edges and in cracks and holes can be used. Except where stronger stoppings are necessary, wood is generally not as desirable as brattice cloth for temporary stoppings or seals. More time is required for construction and, unless the entire surface of a wood stopping is plastered, it is little if any tighter than a well-constructed brattice-cloth stopping. Temporary stoppings should be set from 1 to 2 metres (3 to 7 feet) or more inside openings to be sealed, to allow enough room to erect permanent stoppings outside them.

In summary, stoppings can be built in a variety of ways, including:

- Burlap sacks filled with fine waste materials (Plate 8-4).
- Waste materials dumped and bulldozed to the back.
- Waste material with brattice cloth hung to close the upper portion, as in Figure 8-19.
- Urethane foam (rigid) sealed stoppings.

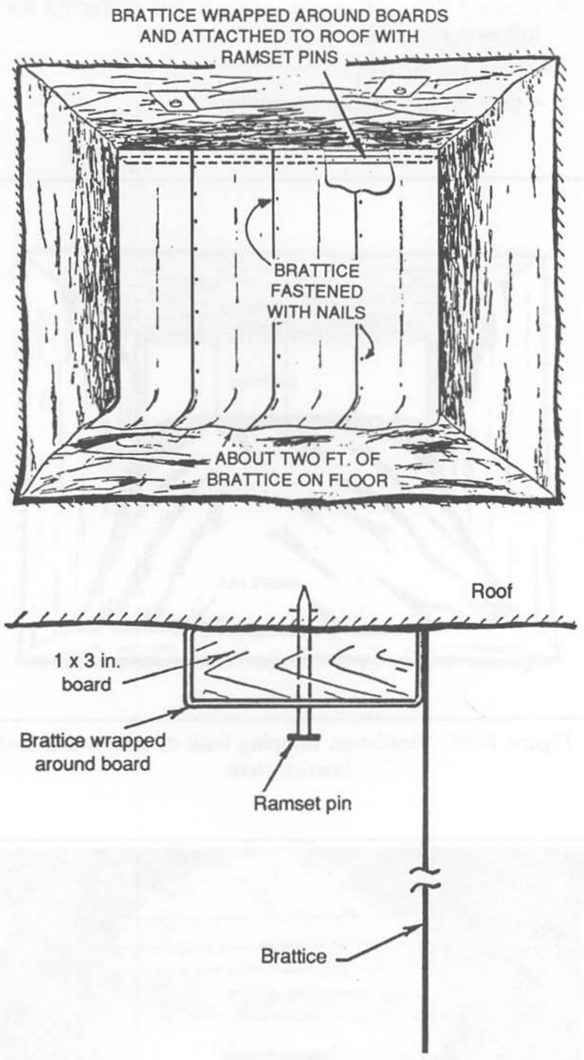


Figure 8-18. Construction of a ventilation stopping using brattice cloth.

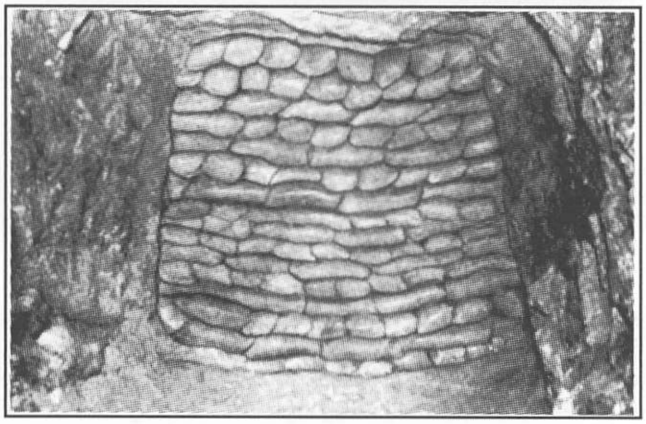


Plate 8-4. A ventilation stopping built with burlap sacks filled with fine waste materials.

- Concrete and wood stoppings (Plate 8-5).
- Brattice cloth or plastic brattice are preferred for the following reasons:
  - they are airtight.
  - they do not absorb moisture.

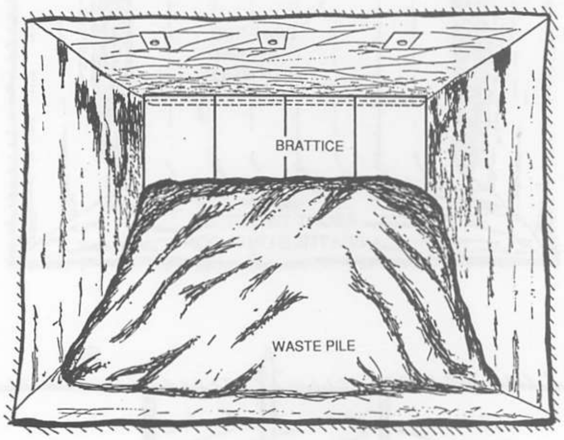


Figure 8-19. Ventilation stopping built of mine waste and brattice cloth.

Plate 8-5. A ventilation stopping built with wooden boards. The escape door will be sealed when all rescue workers have left the area to be sealed.

PERMANENT STOPPINGS

The character of the permanent stoppings or seals for sealing a mine fire depends on the materials available, the length of time they are to be in use, the necessity for complete airtightness, and the strength required to withstand pressure or crushing. Permanent stoppings or seals may be built of brick, cement blocks, concrete, tile, wood plastered with wood fibre, mud and cement or cement mortar, wood with a layer or two of brattice cloth or tarred felt between layers of planks, or pack walls of various kinds.

Permanent stoppings erected as fire seals should be well hitched into the ribs, roof and floor and built snugly into the hitches to make them as tight as possible. Provision should be made for collecting air samples, taking water-gauge readings and bleeding off excess pressure of fire gases by placing a pipe or pipes with suitable valves in one or more of the stoppings. It may also be advisable to provide pipes and valves in some of the stoppings for the purpose of flooding or draining the fire area.

A pipe for collecting air samples may be placed anywhere in a stopping, as after the gases are diffused the same mixture is likely to be found anywhere behind the seals. For convenience the pipe is usually placed near the centre of the stopping. The number of stoppings in which pipes should be placed for collecting air samples will depend upon the area under seal, the number of stoppings used to seal the fire and their position.

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

EXPLOSION-PROOF FIRE SEALS

In order to prevent the occurrence of an explosion during sealing, a ventilation tunnel can be used to prevent an accumulation of flammable gas within the area.

It is desirable to construct a stopping which is capable of withstanding a pressure of 175 to 350 kilopascals (25 to 50 psi), which can be developed within a sealed-off area.

A well-built sandbag stopping 8 to 9 metres (25 to 30 feet) long is considered sufficiently explosion proof even for large roadways (Figure 8-20). Girders laced across the stopping should be used as reinforcements. A tunnel must be incorporated in this type of seal to allow for the final sealing. Originally this was a sandbag tunnel, but as a result of experience and experiment, Butterley steel tubes (access tubes) have been introduced and are now used where it is intended to reopen the area. The final closing of the inflow end of the seal is by a submarine-type hinged door, with a large steel coverplate at the outflow end.

Any type of tunnel used should be large enough to allow personnel wearing self-contained breathing apparatus to pass through it easily.

An alternative explosion-proof stopping, using brickwork and rubble filling, is illustrated in Figure 8-21.

DUTIES OF MINE RESCUE TEAM

It can be seen that there are no set rules for sealing mine fires. It is the duty of the rescue teams to collect as much information as possible about the fire and to relay this information to the person in charge and the advisory committee. In turn it is the duty of the person in charge and the advisory committee to evaluate the information and decide whether to seal the fire or continue to search for trapped or missing persons, but they must consider the welfare and the safety of the rescue teams at all times.

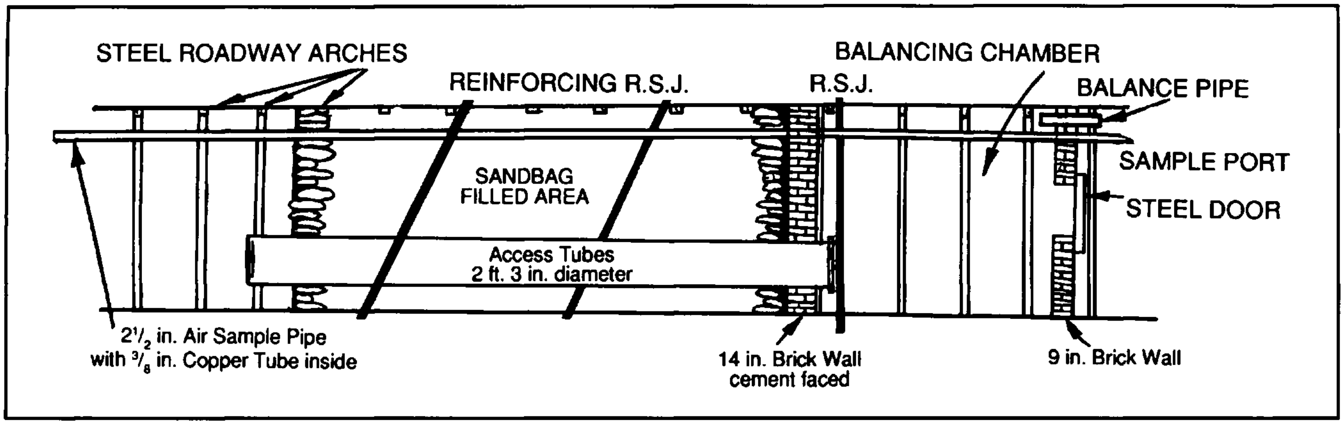


Figure 8-20. Explosion-proof sandbag stopping with Butterley steel access tubes.

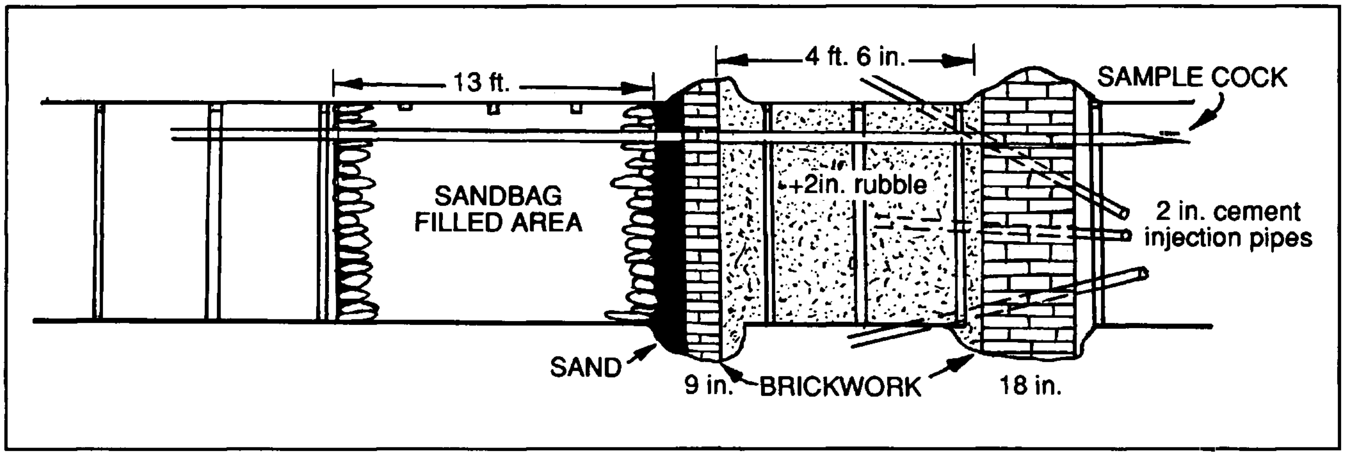


Figure 8-21. Explosion-proof stopping built of sandbags and brickwork with a rubble filling.

UNSEALING MINE FIRES

The question of when and how to unseal mine fires is of vital importance to the mining industry. If a fire area is unsealed too soon, the hazard to life and property is always increased. This dangerous practice has been followed and seemingly continues to be used with unusual frequency, with resulting loss of life and enormous economic losses.

FACTORS GOVERNING TIME FOR UNSEALING

Unsealing any mine fire is dangerous and should not be treated lightly by those engaged in the work. Although a sealed area containing explosive gases undoubtedly presents the most dangerous condition, all mine fires should be considered as potential hazards when the time for unsealing them arrives. Besides making sure of the proper time for unsealing the fire area, those doing the work should be safeguarded in every possible way. Experience and scientific study have shown that no attempt should be made to unseal a mine fire until:

- The oxygen content of the sealed atmosphere is low enough to make explosions impossible, irrespective of the amount of combustible gases or dust that may be present.
- Carbon monoxide, the indicator of combustion, has disappeared.
- In addition, the sealed area should be given time to cool, to minimize the chance of rekindling when air is admitted.

The principal factors that govern the time for unsealing fires areas, as gained from personal experience, observation and consultation with experienced miners, are:

- Extent and intensity of the fire at the time of sealing.
- Character of burning materials.
- Tightness of seals in the closed area.
- Effective barometric pressure in the sealed area.
- Effective temperature in the sealed area.
- Position of the fire area with respect to ventilation.
- Sampling and analysis of the atmosphere under seal.
- Composition of fire gases in the sealed area.

METHODS OF UNSEALING MINE FIRES

The method to be used for the recovery of a fire area must be planned in detail by the control centre before the seals are broken. In general, two systems are used:

- Recovery in successive blocks by means of air locks.
- Reventilation after there is conclusive evidence that the fire has been extinguished.

When the sealed area is extensive and the fire is inaccessible, or the urgency of the situation necessitates the removal of bodies from the site of a previous explosion, the area should be rehabilitated in sections by using air locks and advancing to a point where observations can be made or the bodies recovered. An air lock consists of two stoppings 3 to 5 metres (10 to 15 feet) apart, equipped with doors through which crews wearing oxygen breathing apparatus can enter and carry material into the sealed area. One door of the air lock is kept closed at all times.

When an air lock is complete, the crews can pass through it and erect another air lock about 60 to 150 metres (200 to 500 feet) further into the workings and do such other work as may be required for the rehabilitation of the area between the air locks. The distance between air locks depends on conditions encountered, such as ease of travel, height of the workings and work to be done. As an area between air locks is rehabilitated and locks have been built close enough to the seat of the fire to allow observations to be made, it may be possible to remove heated material through the air locks; this has been done at some fires.

When the sealed-off area is relatively small and can be explored by rescue crews under reasonably safe conditions, and when there is every indication that the fire is out, the area should be reventilated and the fire gases removed as quickly as possible, preferably with all persons out of the mine.

It must always be remembered that an air-locking operation should never be undertaken until the oxygen content of the air in the area behind the seals has been reduced to at least 2 per cent, particularly in a gassy mine. The lower the oxygen content within the sealed area before the air-locking recovery is started, the less likelihood there is of interruption once the work is begun. Owing to the unavoidable infiltration of normal air, the oxygen content of the atmosphere behind the seals will increase and, if explosive mixtures of certain gases are encountered, an explosion is possible.

RECOVERING A SEALED AREA BY VENTILATION

When a decision has been made to recover a sealed area by direct ventilation, an air lock should be constructed, preferably near the intake seal. A rescue crew, using a lifeline and fully equipped for the work at hand, should break the seal, enter, observe conditions, take temperature readings and air samples, and return to the fresh-air base. If the observations and examination of the affected area have shown that conditions are favourable, then return seals should be broken by an apparatus crew and the air lock opened to admit air. The area should be ventilated, but the combustible gases in the main return should, if feasible, be kept below the lowest explosive limit.

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

MINE EXPLOSIONS

Up to this point this chapter has dealt mostly with mine fires. The procedure for recovery following mine explosions is much the same and the duties of all involved are summarized in the following pages.

An efficient organization, appropriate and adequate equipment and materials, and correct procedures, are of prime importance in conducting safe rescue and recovery operations after a mine explosion. Improper procedure may sacrifice any possible chance of rescuing survivors and may also result in loss of life of recovery workers.

As soon as possible the fan should be inspected and kept running with an attendant in charge; electric current should be cut off from the mine, mine entrances guarded and roped off, and a system of checking in and out established. Rescue and recovery crews, with other personnel and necessary equipment and material, should be assembled promptly.

EXAMINATION OF MINE OPENINGS

Before exploration begins, a preliminary examination should be made of all openings and escapeways, as men overcome by toxic gases or oxygen deficiency may be found near openings.

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

ESTABLISHING VENTILATION

If the ventilation fan has not been destroyed or damaged, it should be kept running; with the fan running normally, ventilation will be established only to the point where stoppings have been destroyed by the force of the explosion.

The ventilating current should not be reversed without good reason, and then only on written orders by those in charge; this is of vital importance, particularly if any survivors are known to be alive in the mine. If it is impossible to operate the fan, repairs or replacements should be made immediately, as little or no recovery progress can be made without adequate ventilation. Advantage should be taken of any natural ventilation that may be established, to make a preliminary examination around the mine openings and for a short distance inside the mine.

ENTERING THE MINE AND ESTABLISHING THE FRESH-AIR BASE

When the necessary organization has been set up, equipment and materials assembled, and ventilation established, exploration of the mine can begin. The officials in charge of the shift should check the crews going underground to see that everyone is properly equipped and that only persons whose skills may be of definite use are allowed to go into the mine.

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

ESTABLISHING TELEPHONE COMMUNICATION

When crews are advancing, portable telephones may be useful to keep in touch with the surface control centre. A standard telephone, connected to the surface control centre, should be installed at the fresh-air base with an operator always present. Only telephones specifically approved for use in coal mines will be used in coal mine rescue operations. As recovery work progresses the telephone system should be extended so that a telephone is always within easy reach of the advancing crew. Ordinary telephones should not be installed or left where they may come in contact with explosive gases.

DUTIES OF RESCUE AND RECOVERY CREWS

Rescue and recovery crews are specialized teams with duties quite different from everyday underground crews. Members of rescue crews are equipped with gas masks or oxygen breathing apparatus and are specially trained and equipped to explore and perform work in a hostile environment of irrespirable air and, when the occasion arises, rescue survivors. Recovery crews are comprised of bratticemen, men for handling and transporting material and bodies, drivers, telephone attendants, timbermen, trackmen, road cleaners, and other tradesmen.

Rescue crews work in close cooperation with recovery crews by exploring ahead of fresh air to reach survivors, locate bodies, test the mine air, look for fires, and erect stoppings when respiratory protection is required. Men wearing breathing apparatus should not transport bodies except in an emergency, and then only for short distances. People who have not worn oxygen breathing apparatus often ask rescue crews to perform duties that should not be required of those who do this very arduous and dangerous work.

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

EXPLORATION AHEAD OF FRESH AIR

After a fresh-air base has been established, exploring should be done ahead of fresh air by rescue crews wearing oxygen breathing apparatus, to look for survivors and fires, locate bodies and observe conditions. It is always advisable to make short trips ahead of fresh air [about 75 to 125 metres (250 to 400 feet)] as experience has shown that more can be accomplished, and the work done more safely by this method than by long and dangerous trips far in advance of fresh air. Long exploration trips should not be made unless they are essential to save lives or to do other work absolutely necessary for the continuance of recovery operations. Exploration trips ahead of fresh air may be made by crews wearing gas masks if it is known with a fair level of certainty that masks can be used safely. Crews equipped with oxygen breathing apparatus should be held in reserve to support gas-mask crews in conditions where gas masks cannot be worn with safety. When gas-mask or oxygen breathing apparatus crews are working ahead of fresh air, another oxygen breathing apparatus crew, fully equipped with apparatus adequately charged and in good condition, should always be held in reserve at the fresh-air base.

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

CONTROL OF VENTILATION

The procedure of alternately exploring ahead of fresh air and advancing the air by erecting temporary stoppings should be continued until the entire area affected by the explosion has been recovered.

In ventilating any part of a mine after an explosion, the "after damp" should be conducted to the outside by the most direct route. Allowing the poisonous gases to move through other sections of a mine may seriously endanger the lives of survivors or crews engaged in rescue and recovery work.

Safe practice requires that currents of air be directed in such a way that ventilation will always be under the control of the shiftboss and the paths the air is traveling will always be known with certainty. It is extremely dangerous after an explosion, especially in a gassy mine, to permit air to travel over or through unexplored areas of the mine. Unless this vital precaution is taken, an explosive mixture of gas may be brought into contact with a fire, causing another explosion, possibly with disastrous effects; this has occurred in several cases.

All sections, entries, rooms, stopes and other open accessible workings should, if possible, be cleared of "after damp" as work advances. If this is not done fires may be bratticed off and reach a serious stage before discovery, or explosive, asphyxiating or poisonous gases may seep from bratticed-off areas, enter the ventilating curent and contaminate the area where recovery work is in progress, seriously affecting members of the rescue or recovery crews or possibly causing another explosion.

Line brattice will be required for ventilating faces of entries and rooms or when it is necessary to split the air current in entries. If a brattice is required for a considerable distance, it should be erected by setting posts about 2.5 to 3.5 metres (8 to 12 feet) apart in the centre or on one side of the passageway, and the brattice cloth nailed to them. When a short-line brattice is required to clean out the face of a working place, it can be done quickly by having a number of men hold the brattice cloth in place instead of fastening it on posts.

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

If fires are found while rescue crews are exploring ahead of fresh air, they should be extinguished, if possible, with water, rock dust or fire extinguishers, before the fresh air is advanced to the fire. When the fire is too big or too inaccessible to be put out quickly and easily, it should be sealed promptly and effectively.

If smoke and an explosive mixture of gas are encountered and the location of the fire is unknown, it is advisable to seal the area containing the fire, or the entire mine, immediately.

In conclusion, it can been seen that fighting fires, or recovery work after explosions, is no easy task. If it is to be successful, every person who works in a mine, regardless of size or type, either coal or metal, must realize that these hazards exist as long as something that will burn is present underground. All underground workers should receive training in survival through a disaster of this nature. It can be seen that continuous and extensive training is a must for those who participate in the actual rescue and recovery operations.

CHAPTER 9

EMERGENCY IN UNDERGROUND MINING OPERATIONS

TRAINING OBJECTIVES

This short chapter will familiarize rescue trainees with reporting procedures in the event of mine emergencies, the importance of planning ahead for all possible emergency situations, and the provision of refuge stations underground. It will also suggest how authority for different aspects of the emergency response plan should be delegated.

REPORTING PROCEDURES

When the mine manager receives word of a mine emergency he should assess the situation immediately and notify the following:

District Mines Inspector	Telephone: Office ....
Chief Inspector of Mines, Victoria	Telephone: Office 356-2200

The Chief Inspector of Mines will alert backup services and the District Mines Inspector will travel to the mine.

When sufficient information has been received, the Chief Inspector of Mines will decide what additional backup will be required. Should a serious situation develop, a call will be sent out for immediate assistance, which will result in equipment and personnel being sent to the site within hours or minutes.

Six Mine Rescue Stations are equipped and maintained by the Ministry of Energy, Mines and Petroleum Resources (*see* Emergency Equipment and Mine Manual — Section M.B.):

Location	**Telephone**
Fernie	Office: 423-6884
Kamloops	Office: 828-4566
Nanaimo	Office: 755-2560
Nelson	Office: 354-6125
Prince George	Office: 565-6125
Smithers	Office: 847-7387

The *Emergency Equipment and Personnel Manual* (red book) will be referred to by the Chief Inspector of Mines when immediate contacts for backup rescue teams, breathing apparatus, auxiliary supplies and equipment are required. In addition, the following local support personnel and service organizations are prepared to respond:

Resource Organization	**Resource**	**Telephone**
Provincial Emergency Program, Director	Accommodation (mobile) Communications systems Lighting systems Medi-Vac services Food, blankets, stretchers, etc. Transportation (buses)	Victoria 387-5956 (24 hour)
Canada Research Council, *Peter Schaerer*	Avalanche rescue	Vancouver 666-6741 (office) 987-3617 (home)
Ministry of Transportation and Highways, *Geoff Freer*	Senior avalanche coordinator	387-6361 (office) 383-6610 (home)
Emergency Health Services, Regional Unit Officers	Ambulance services Helicopter Fixed-wing aircraft	Victoria and Vancouver 911
R.C.M.P. Regional Detachment	Investigations Medical evacuation services Helicopter Fixed-wing aircraft	Victoria and Vancouver 911
Canadian Liquid Air	Nitrogen (inerting) Liquid and compressed oxygen	Victoria 388-5406
Gas Analysis Services, Cantest Labs, *Dave Dyck*, *Gordon Polley*	Portable gas testing and analysis equipment	Vancouver 734-7276 (office) 667-2687 (emergency pager)
Enviroscience Products *Dale Brewer*		734-4211

NOTE: This emergency response sheet should be updated on an annual basis, more frequently, if necessary. Fill in telephone numbers for regional resources where applicable.

A GUIDE FOR PLANNING MINE EMERGENCY PROCEDURES

Although the planning of mine emergency procedures is beyond the scope of rescue training, the following information is provided as a guide for those who must plan such procedures. A study of this guide will make it more apparent to underground workers why it is essential that all the prescribed emergency procedures are followed as closely as possible.

The effective implementation of all mine emergency procedures is an intricate operation and many people and organizations are involved. If all concerned do not follow their part of the plan as closely as possible, there will be utter confusion and unnecessary loss of life and property may result.

BASIC POLICY

The first priority of all underground emergency procedures must be THE SAVING OF LIVES. This effort must be continued until all underground workers are accounted for and have been brought to the surface. The prompt reporting of fires is essential to achieving this objective.

REPORTING FIRES

All underground employees must be instructed in their immediate course of action in the event that they discover a fire, or encounter signs that a fire or explosion has taken place. These instructions must be clear, concise and uncomplicated. They should be given to all employees during their indoctrination period and should be reviewed frequently with supervisors. The instructions should also be written out and posted in conspicuous places where workers frequently congregate, such as mine drys, shifter's offices, lunchrooms, shaft stations and underground shops.

The first action of anyone finding a small or incipient fire should be to attempt to put it out. For this reason, every underground worker must have a basic knowledge of firefighting. Instructions to employees must be explicit about the time to be spent fighting a fire before it is reported. This should not be more than a few minutes. If after this time the fire is not definitely under control, then it must be reported.

The procedure for reporting a fire will vary from mine to mine, but the initial report will usually be made by telephone. The person who first becomes aware of a fire should go quickly to the nearest telephone that can be safely reached. For this reason all employees must be familiar with the location of telephones. Telephone locations should be noted on mine plans posted in the mine. The number to call to report a fire must be known to all personnel and should be posted at all telephone locations. It must be a station at which someone is always on duty. Such stations may be the main power house, security gate, hoistroom, machine shop, warehouse and telephone switchboard.

The initial message should be concise. The fact that a fire exists, its location, and the name and location of the person giving the report is all that is initially required. An example of this first report would be:

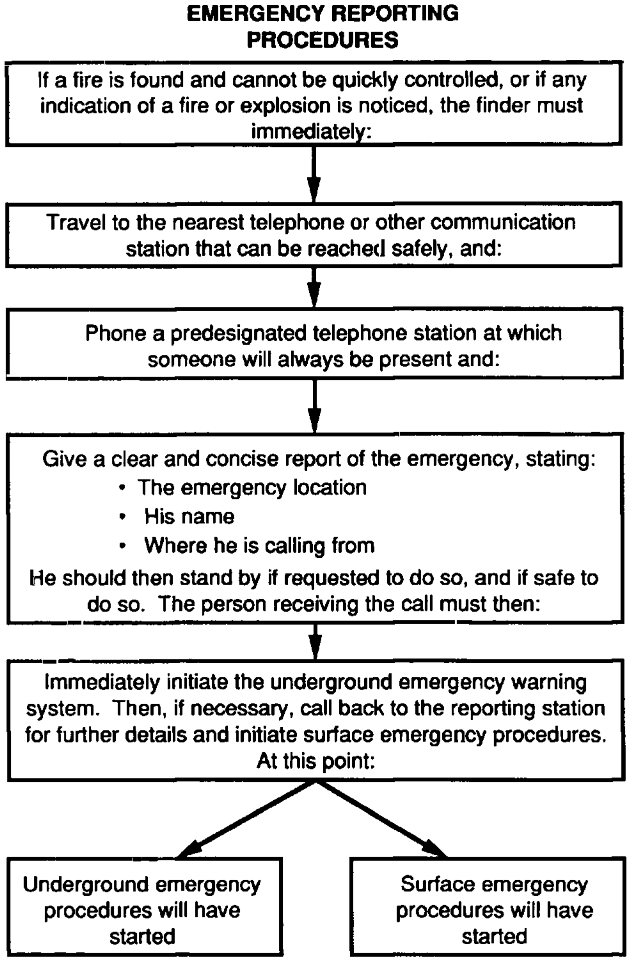
> "Fire underground at 2100-level transformer station. My name is Joe Doe calling from 2100 No. 2 shaft station."

Once the fire reporting station has received such a message, the immediate concern of the person receiving the call will be to initiate the underground fire warning system. They may, however, ask the person reporting the fire to stand by at the telephone, if safe to do so, and provide further details. Further details can be obtained after the general warning has been given.

The person receiving the fire report must immediately initiate the general mine warning system. Probably the most efficient warning system in common use is the stench-gas system. The method used, however, must be capable of reaching all underground workers in the shortest possible time. It cannot be overemphasized that this warning must be given without delay.

Once the mine warning system has been activated, the person who received the call may wish to call back to the person who reported the fire and request a more detailed report. At this time underground emergency procedures will have started and surface emergency preparations must be begun.

A summary of emergency plans which must be made to this point is provided in Figure 9-1.



EMERGENCY REPORTING PROCEDURES

If a fire is found and cannot be quickly controlled, or if any indication of a fire or explosion is noticed, the finder must immediately:

Travel to the nearest telephone or other communication station that can be reached safely, and:

Phone a predesignated telephone station at which someone will always be present and:

Give a clear and concise report of the emergency, stating:
- The emergency location
- His name
- Where he is calling from

He should then stand by if requested to do so, and if safe to do so. The person receiving the call must then:

Immediately initiate the underground emergency warning system. Then, if necessary, call back to the reporting station for further details and initiate surface emergency procedures. At this point:

Underground emergency procedures will have started

Surface emergency procedures will have started

Figure 9-1. Reporting procedures for underground mine emergencies.

The emergency procedures plan thus far is quite straightforward. It must, however, be worked out in detail and all employees must be familiar with it. The people who staff the station to which emergencies are reported must be thoroughly familiar with the mine emergency warning system and the part they must play in the follow-up plan.

UNDERGROUND EMERGENCY PROCEDURES

When underground workers smell the warning stench gas or otherwise receive warning of an underground emergency, they must know exactly what to do. The actions to be taken must be planned in detail and the plan must be communicated to all workers. Generalized statements such as "Get out of the mine" or "Seek a refuge station" are not good enough.

Plans of action will vary from mine to mine and from place to place in any one mine. Consideration must be givan to:

- Primary escape routes.
- Secoudary escape routes.
- Location of refuge stations.
- Location of self-rescuer caches.
- Normal mine ventilation.
- How fires in various areas of the mine may affect normal ventilation.
- How main fan stoppages may affect ventilation.
- Auxiliary fans; should they be shut down or left running.
- Ventilation doors and regulators; shonld they be open or closed.
- Location of fire doors.
- Equipping refuge stations; air, water, telephone, oxygen-generating equipment, first aid supplies, self-rescuers.
- Any and all factors that could affect the safety of workers underground during times of emergency.

As mentioned, the plan of action for underground workers will vary from mine to mine. For example, the initial action in one mine may be to attempt to escape by a primary travel route, while in another mine it may be to immediately seek a refuge station. Whatever the plan, all pertinent factors must be considered and **once the plan is adopted it must be communicated to all workers**.

The underground emergency plan must be reviewed frequently and kept up to date. Underground crews must have regular reviews of the procedure so that they are always aware of the action necessary for the part of the mine in which they are working.

SURFACE EMERGENCY PROCEDURES

The last part of the instructions to underground workers is the action they should take on reaching the surface. At this point the underground procedures become a part of the surface procedures.

ASSEMBLY AREA

When workers reach the surface they must check out of the mine using the established man-check system. They should then assemble in a predesignated area and should not leave until told to do so by a person in authority. The surface emergency procedures plan must therefore designate such an assembly area and it must be known to all workers. It must also specify who is in charge of the area and what his or her responsibilities are.

Miners should also be instructed not to speak to members of the press about their experience underground. If exaggerated stories of the mine emergency are publicized, much unnecessary anguish will be caused to the families of others who may be trapped in the mine.

NOTIFICATION OF KEY PERSONNEL

The person who first received the fire report and initiated the mine emergency warning system must now set the surface emergency procedures plan in operation. Key supervisory staff must be notified of the emergency and definite procedures for doing this must be established. The staff in the fire reporting station must be thoroughly familiar with the procedure.

Probably the best general procedure is to have this person notify a minimum number of key people and they, in turn, notify those who will be working under their supervision during the emergency.

The person at the fire reporting station may, for example, notify the mine manager, the mine superintendent, the chief engineer, the plant superintendent and the safety supervisor. Whoever this person must notify, he must know how to reach them. The telephone numbers of these officials must be posted at the reporting station and, of course, this must include both their telephone number at the mine and at their homes. These telephone numbers must be accurate and up to date. If key people cannot be reached then alternate personnel must be called and the alternate telephone numbers must also be listed.

MANAGEMENT RESPONSIBILITIES

The following is an outline of the functions that must be planned for, and suggestions as to who shonld most logically be in charge of each function. In any event, the person in charge of each function should be the one best qualified for the job (Figure 9-2).

MINE MANAGER

On receiving a report of a mine emergency the mine manager must assess the information immediately available and notify the District Mines Inspector and the Chief Inspector of Mines. The Ministry of Energy, Mines and Petroleum Resources will initiate its backup services and the District Inspector will immediately travel to the mine. The mine manager will then take charge of the emergency coordination centre.

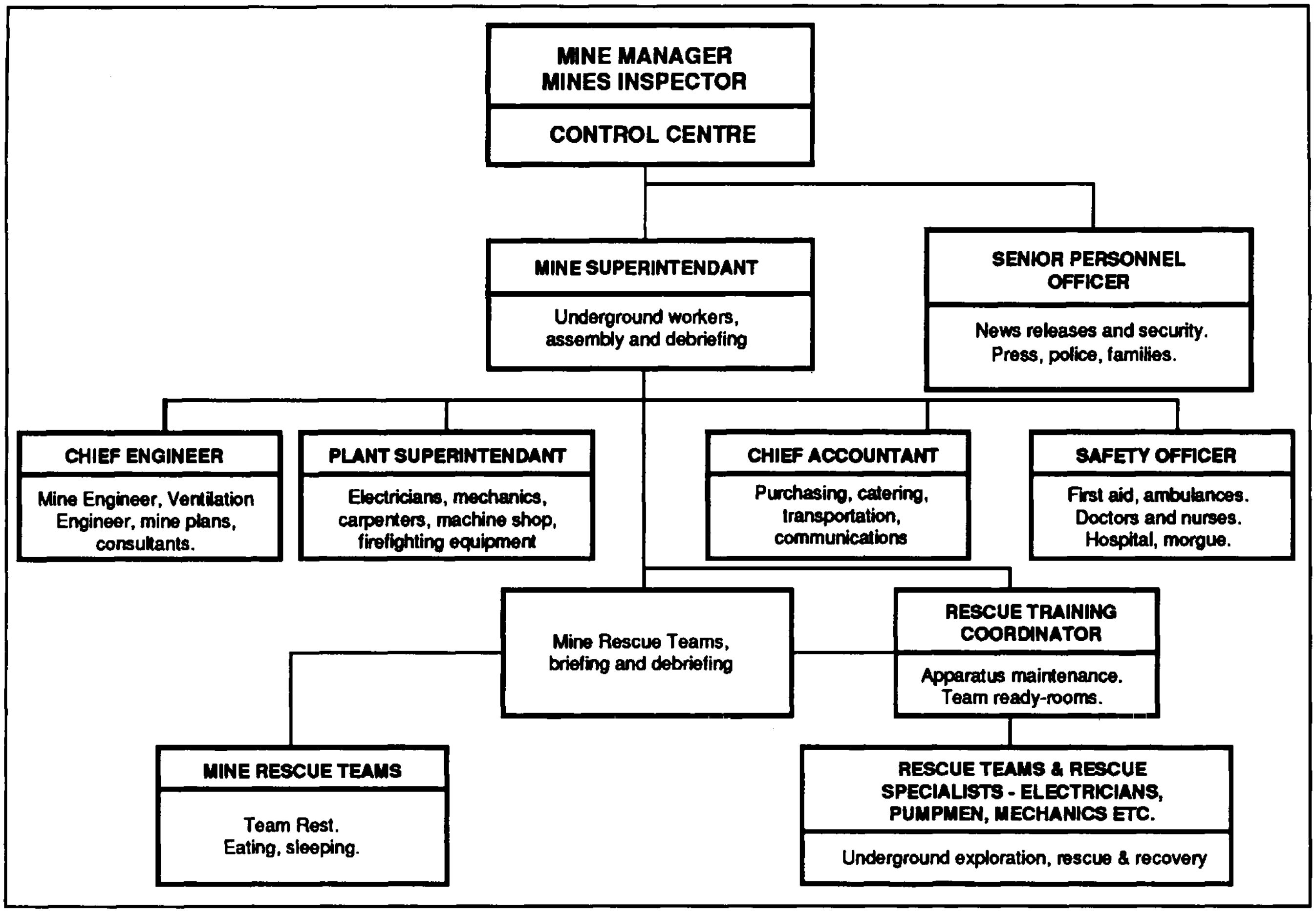


Figure 9-2. Delegation of authority in mine emergency planning.

The mine emergency coordination centre must be a predesignated area with a good telephone communication system and ready access to all mine plans and other technical data which may be required during the emergency. The mine manager and the mines inspector (on his arrival) will jointly direct the overall emergency rescue and recovery operations.

A logical choice of a coordination centre is the mine engineering office. Access to this centre during the emergency must be strictly controlled and should be limited to necessary personnel only. The location and security of the coordination centre must be planned in detail and all persons concerned must be thoroughly familiar with their functions. Plans must also be made for keeping a detailed and accurate record of the progress of the emergency operation.

As the mine manager, jointly with the mines inspector, has overall responsibility for the rescue and recovery operation, he will have many aspects of the operation to coordinate. He cannot personally direct every activity and must delegate specific responsibilities.

MINE SUPERINTENDENT

The mine superintendent, or any other senior mine supervisor, is best suited to direct the actual underground part of the operation as his involvement in the day-to-day supervision of the mine will give him a detailed and current knowledge of the mine workings.

The first responsibility of the superintendent is to ensure that all workers who leave the mine are checked out and accounted for. The cooperation of all first-line supervisors will be required to accomplish this. These first-line supervisors will include the mechanical foreman, electrical foreman, chief surveyor and shiftbosses. When all underground workers have been accounted for the mine superintendent can focus on other aspects of the emergency.

If all workers are not safely accounted for then the superintendent, together with the first-line supervisors, must determine where the missing are most likely to be found and rescue efforts must begin. It is important, therefore, that a good tally system of all workers in the mine be maintained, and that all employees are instructed in its use.

When miners reach surface the mine superintendent should see that they are debriefed and that all available information is assembled. This information is then passed on to the coordination centre where decisions will be made regarding how rescue and recovery operations are to be conducted.

Once the initial mine evacuation has been completed the mine superintendent will work with the coordination centre making decisions regarding the nature of the recovery operation. He will also act as liaison between the coordination centre and the mine rescue team briefing room. He will give instructions to the mine rescue teams when they leave the mine. Some of these duties can, of course, be delegated to responsible persons working under the superintendent.

CHIEF ENGINEER

Current mine plans and mine ventilation plans must be available in the disaster coordination centre and for use by mine rescue teams. In addition, technical advice regarding mine ventilation, mechanical installations, etc. must be readily available. The chief engineer is the most logical person to provide these services.

The chief engineer should have the surveyors, ventilation engineer and planning engineers working under his supervision to meet these requirements. Outside consultants may be called in to assist with technical problems. The chief engineer should coordinate all these personnel and act as liaison between them and the coordination centre.

The requirements of this phase of the disaster organization must be worked out in detail in advance, and everyone must know their function.

FIRST AID AND MEDICAL SERVICES (SAFETY SUPERVISOR)

At the time of a mine disaster workers may be injured, exposed to harmful gases or burned. It is imperative that a detailed plan be prepared for providing first aid and medical services. A large number of injured may require treatment and the normal first aid facilities at the mine will probably be inadequate. A place must be chosen that will serve as an expanded first aid centre. Additional staff trained in first aid and a source of extra first aid supplies must be available.

Ambulance services must be available and, once again, the normal ambulance service at the mine will probably not be adequate. A source of additional ambulance vehicles must be prearranged.

Emergency medical aid must be preplanned, either at the nearest hospital or at some other convenient location. Available doctors and nurses in the area should be made aware of what may be required of them in the event of a major mine disaster. Emergency transportation to major medical centres must also be considered, including the availability of air ambulance services. A facility to serve as a morgue must be planned.

The planning for and operation of the required first aid and medical services are logically supervised by the mine's safety supervisor. Once again plans must be made in detail and everyone concerned must know what their duties will be.

EMERGENCY SUPPLIES AND SERVICES (PURCHASING DEPARTMENT)

After a major mine emergency many supplies will be required in quantities not normally kept in stock at the mining property.

The emergency preplanning should include making a list of all items that may be required and making prearrangements for purchase and delivery of these supplies in the event of an emergency. It should consider what is the best and quickest source of such things as compressed oxygen, liquid oxygen, carbon dioxide absorbent, first aid supplies, brattice cloth, fans, foam-generating equipment, portable communication supples and so on. Any and all materials that may be required should have a ready source and means of delivery noted in the mine emergency plan.

In addition, provision must be made for supplying food, bedding and other conveniences for mine rescue teams and for all other personnel involved in the emergency work. Specific rooms must be set aside for resting and feeding rescue workers and a plan worked out for supplying properly prepared food and refreshments.

Controlling the use of existing telephone or radio services and arranging for additional emergency services must be preplanned.

Transportation of emergency supplies, additional rescue crews and consultants must be planned in advance. What transportation facilities are available? Who should be contacted for additional rescue teams? What consultants can be called, how are they reached and how will they be transported to the mine?

The answers to all these supply and service questions should be known in advance and someone must be responsible for initiating actions. The most logical person to coordinate these activities is the person normally responsible for purchasing of supplies, for example, the chief accountant or purchasing agent.

ON-SITE SERVICES

The repair and servicing of on-property electrical and mechanical equipment and buildings must be provided for. The plant superintendent would most logically be in charge of mechanics, electricians, carpenters and other tradesmen. Plans must be made in advance, detailing services and functions that may be required and who will provide them.

INFORMATION CENTRE AND SECURITY

In the event of a major emergency, someone must be responsible for releasing information to the police, to the press and to families of trapped men. This is a very delicate task and must be handled with a great deal of tact. A general policy should be worked out and the person providing this service must work very closely with the emergency coordination centre.

At the time of a mine emergency, property security becomes very important indeed. Unauthorized persons must not be allowed on the property and there must be strict control of persons leaving the property. Extra security staff will probably be required.

The choice of the person to be responsible for information releases and security is very important. The most likely candidate for this job would be the company's senior personnel officer.

MINE RESCUE APPARATUS MAINTENANCE

If the mine emergency entails the use of rescue breathing apparatus then a competent person must be in charge of servicing and maintenance of the apparatus.

The Ministry of Energy, Mines and Petroleum Resources' mine rescue training coordinators are best qualified to provide this service and are available on short notice to carry out this function. The rescue training coordinators have extra rescue breathing apparatus and the spare parts, testing equipment and tools necessary for this work. They have an intimate knowledge of all rescue breathing apparatus. Their expertise and experience should be sought at an early stage of any mine emergency.

This summary cannot begin to lay out all the details of mine emergency planning. It should, however, provide a guide to making such plans. It is important that authority be designated for all required functions and that the physical facilities necessary for each function be provided. Alternates must also be available for all functions.

Everyone must be aware of their role in a mine emergency and must be ready to carry out their part at a moment's notice.

PLAN THE EMERGENCY PROCEDURES.
COMMUNICATE THE PLAN TO ALL EMPLOYEES.
KEEP THE PLAN UP-TO-DATE.
DO NOT DELAY INITIATING THE EMERGENCY PROCEDURES.

REFUGE STATIONS

If, during a fire of after an explosion, emergency escape from the mine is impossible or imprudent, miners must seek a place where they can isolate themselves from toxic gases, smoke and oxygen-deficient atmospheres. Such places are called refuge stations. A mine may have permanent, prepared refuge stations at strategic locations or the miner may have to improvise a refuge station.

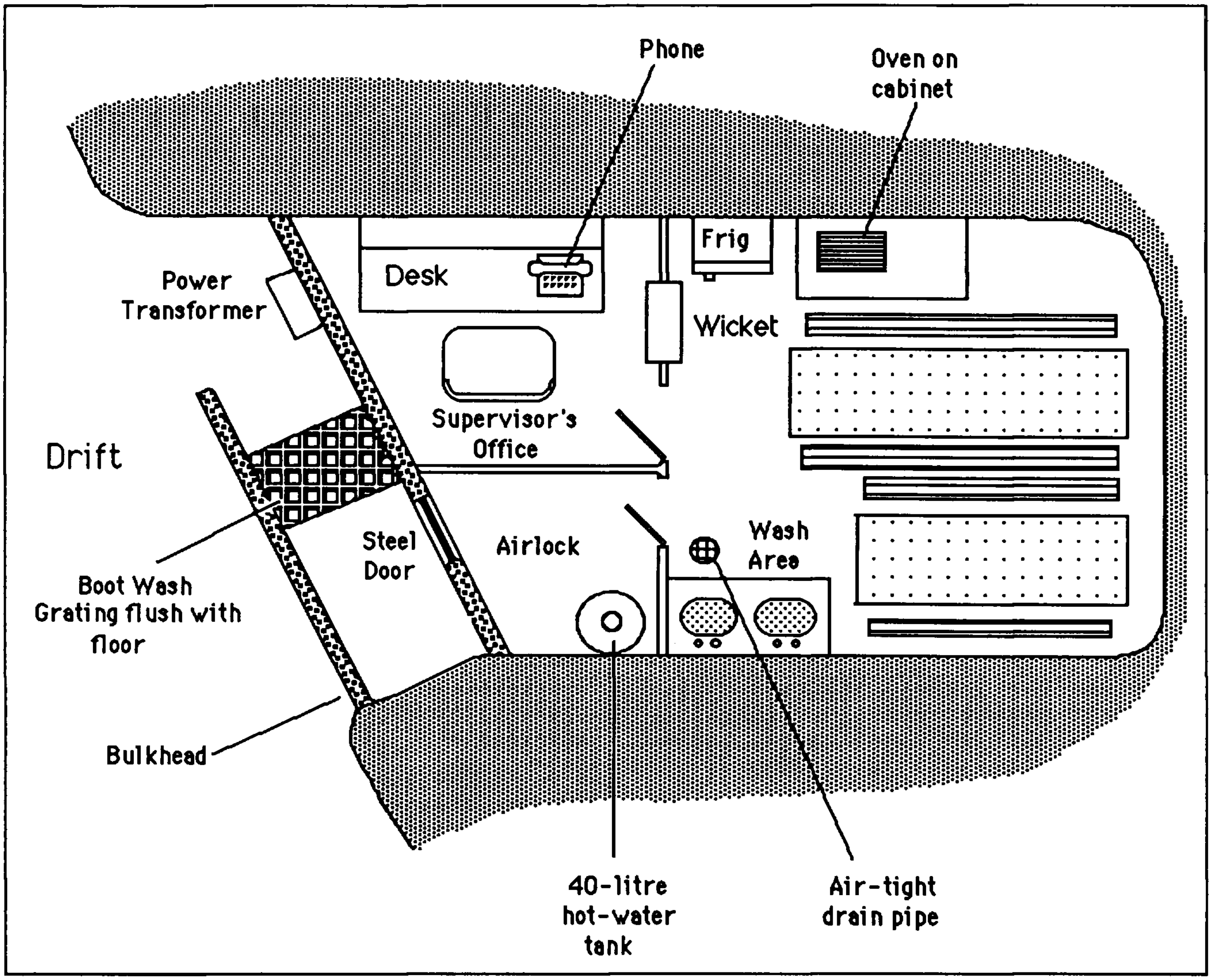


Figure 9-3. A typical underground refuge station (not to scale).

PERMANENT REFUGE STATIONS

When a mine's emergency procedures plan is being prepared it may become apparent that under certain disaster situations all workers in a mine may not be able to reach the surface safely. Under such circumstances permanent refuge stations will be located at strategic places in the mine so as to provide a place of refuge in areas from which escape may not be possible.

A refuge station can serve other purposes as well. Underground lunch rooms, tool cribs and repair shops can be constructed and equipped to serve as emergency refuge stations (Figure 9-3).

Permanent refuge stations will be built in such a way and in such locations that they will protect miners from dangerous gases, fire and gas explosions. They should be equipped with telephones or other emergency communication systems, piped-in fresh air or oxygen-generating equipment, first aid supplies, emergency breathing apparatus, drinking water and such other emergency supplies as circumstances at the mine may dictate. Permanent refuge stations should enable miners trapped underground to survive indefinitely, completely independent of conditions outside the station.

SIZE

The recommended size for a refuge station is 18 cubic metres (24 cubic yards) times the maximum number of workers in the area at any time (Figure 9-4).

CONSTRUCTION

- Bar the walls and back and clean the floor to solid rock.
- Check for cracks or holes which will have to be sealed.
- Install a 15-centimetre (6-inch) concrete or 30-centimetre (12-inch) shotcrete (gunite) seal in all openings and key into the rock.
- Install a concrete or shotcrete floor.
- Install fire door in all doorways after all wood has been removed.
- Seal inlets for air, water and power after installation.
- Exhaust pipe to be threaded and fitted with a cap.
- Floor drains to have a trap.
- Check for airtightness.

EQUIPMENT AND FURNISHINGS

- Compressed air and drinking water (fountain and hose outlet).
- Automatic telephone with emergency numbers posted with index.
- Adequate lighting (fluorescent preferred).
- Heater and warming oven.
- Fully equipped stretcher and first aid box.
- Fire extinguisher.

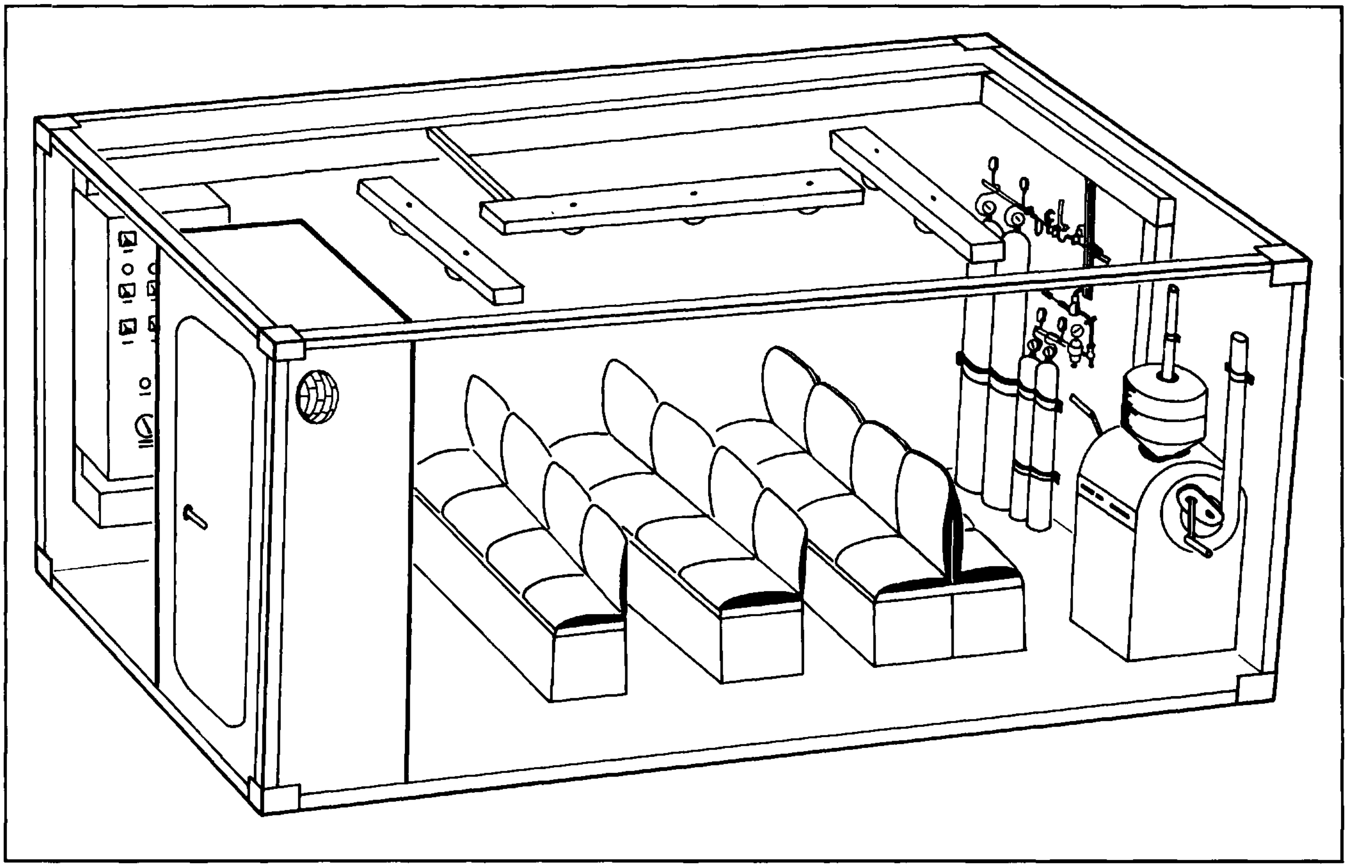


Figure 9-4. A prefabricated emergency chamber designed as a refuge station (Courtesy Safety Supply Co. Ltd.).

- Sealing clay and water.
- Bulletin board with emergency instructions.
- Dining table, benches and clothes rack.
- Sink, with hot and cold water.
- Signs (instructional).

OPTIONAL

Life-support system with chemical toilet, emergency lighting, water, food, blankets, paper, pencils, compressed air and/or oxygen cylinders.

USING A REFUGE STATION

If miners find it necessary to enter a refuge station, the doors must be closed and tightly sealed and should not be reopened except:

- To allow others to enter.
- When directed to do so by mine rescue personnel.

Mine rescue personnel will only direct the station to be unsealed when it is safe to do so.

Before sealing a refuge station a notation should be made on the outside as to how many people are in the station. When they are assembled and sealed in a permanent refuge station they will be safe from the deadly conditions outside. The length of time they can maintain liveable conditions inside will depend on the discipline of the occupants.

As was the case when traveling in the mine, when a group has assembled in a refuge station someone must be appointed to be in charge. This must be a person with leadership ability and with a good knowledge of mine rescue and mine survival procedures. They must maintain good discipline and be able to reassure and calm down anyone in the station who may be claustrophobic or inclined to panic.

The length of stay in the station may be a few hours or it may be for many days. Occupants must assume the stay will be long and their actions must be planned for the longest possible stay. It is far better to be rescued from a station after one day with a surplus of food and water than to be stranded for many days without supplies. The following general guidelines should be used for the conservation of the essentials of life while in refuge stations.

CONSERVATION OF OXYGEN

The refuge station may have piped-in compressed air as a source of oxygen and should also have an independent source of oxygen either in high-pressure cylinders or in the form of oxygen-generating equipment.

As long as oxygen is being supplied by compressed air there is no real concern regarding conservation. If, however, the compressed air supply is interrupted, as may well be the case during a mine disaster, then stringent oxygen conservation measures must be taken.

Oxygen supports the combustion of foodstuffs in the body to produce energy. It follows that the more energy the body is required to produce, the more oxygen is needed. A person at rest, in a calm state of mind, requires far less oxygen than an excited person moving around or otherwise expending energy. The most important rule for conserving oxygen is to remain calm and keep physical activity to a minimum. Everyone should remain seated or lying down (but do not lie on the floor) and should not move about more than is necessary. Someone should, however, move about at regular intervals to check the condition and emotional state of everyone in the refuge station and to physically stir and mix the air.

Remember that carbon dioxide is exhaled when we breathe and is slightly heavier than air. It will therefore tend to accumulate near the floor of the refuge station. For this reason do not lie on the floor because accumulation of carbon dioxide here can displace oxygen to a dangerously low level. It is also for this reason that someone should move about occasionally, to cause a mixing of this carbon dioxide with the general air and avoid it concentrating near the floor.

The refuge station will be equipped with a flame safety lamp or an oxygen-testing instrument. This should be used to monitor the oxygen content of the air.

If compressed oxygen cylinders or oxygen-generating equipment are provided, they should be used according to instructions which will be posted with them and as required by the oxygen tests.

In summary, in order to conserve oxygen and protect survivors in a refuge station:

- Keep calm.
- Physical activity must be kept to a minimum.
- Remain seated or lying down, but do not lie on the floor.
- Someone should move about at regular intervals to stir up the air and to check the physical condition and emotional state of everyone in the station.
- The oxygen content of the air must be monitored at regular intervals and oxygen added to the air from storage cylinders or oxygen-generating equipment as required.
- Smoking must not be permitted.

CONSERVATION OF OTHER RESOURCES

As it is impossible to know how long survivors may have to remain in a refuge station, other resources must also be conserved. Water, food and light should be made to last as long as possible.

If water is piped into the station it should be conserved. The supply of piped-in water may be interrupted and all available containers should be filled with water while it is still available. Water from the pipes should then be used as long as it lasts and the containers kept for emergency use.

If piped-in water is not available or is interrupted, then all water, tea, coffee and other drinks must be strictly rationed. The rationing of water will be the responsibility of the group leader and the amount given out will depend on conditions in the station and the condition of the occupants. Some discomfort from thirst may be necessary in order to make the supply last as long as possible. People at rest require less water than when they are physically active; this is another reason to limit physical activity.

The leader should also gather up all lunch pails and other food supplies and ration them out. Once again, some discomfort from hunger should be allowed in order to make supplies last as long as possible. In the rationing of food and water, special consideration may have to be given to the sick or injured.

The emotional state of miners trapped underground can be greatly affected by a complete lack of light for long periods. When survivors have sealed themselves into a refuge station the leader should gather up all electric hat lamps. These lamps should all be turned off and kept off as long as outside electricity is available for lighting. If the outside power supply is interrupted then the hat lamps should be used one at a time. If a large number of lamps are available it may be wise, at least initially, to keep one lamp burning all the time. When the crew has settled down, then the lamps should be conserved even further by having periods of darkness when all lamps are switched off. The length of the acceptable periods of darkness must be judged by the leader and will depend on the emotional state and physical condition of the survivors.

Any injured survivors in a refuge station must be treated with the first aid equipment at hand. In addition to normal first aid, special attention should be given to the prevention of infection of cuts or open wounds. The reason for this, of course, is that a long wait may be necessary before proper medical attention is available and any minor infection could worsen and become a serious problem during the wait.

Special care and consideration should be given to anyone who may have become emotionally disturbed or irrational. Every effort must be made to keep them calm. In extreme cases, it may be necessary to physically restrain them by tying them up, to prevent them from endangering themselves or others. It may even be necessary to gag a seriously disturbed individual to prevent him from getting others into a state of nervous disorder. Giving highly strung people some responsibility and something to do (even though what they do is unnecessary) will sometimes help take their minds off their worries and help to settle them down.

It can be seen that the responsibility of the group leader is a large one and everyone involved in a disaster should cooperate to the best of their ability. The survival of the whole group depends on calm, rational behaviour.

IMPROVISED REFUGE STATIONS

If escape from a mine is not possible and permanent refuge stations are not provided, then the miners must isolate themselves from dangerous atmospheres by building their own refuge stations. A suitable location should be quickly chosen and a barricade as airtight as possible should be built of any suitable material that is available.

CHOICE OF LOCATION

The choice of location must be the best of those available in the areas that can be safely reached. The area must be easily sealed and should, if possible, have compressed air and water services. To avoid the possibility of flooding it should not be in a low-lying area of the mine.

The ease with which the area can be sealed is of prime importance and an area which requires sealing many openings is not as good as one which requires only one seal. Backfilled areas should be avoided as gases can filter through fill. Heavily timbered areas should also be avoided as it is difficult to effect a good seal over the roof or back of timber sets. Timbered areas are also dangerous as fire may travel through the timber and reach the refuge station.

A primary consideration must be the volume of air contained in the refuge station. A person consumes the oxygen in about 0.75 cubic metre (1 cubic yard) of air every hour. A 3-metre by 3-metre heading 3 metres long (10 feet by 10 feet by 10 feet) contains enough oxygen to sustain one person for 36 hours. The largest amount of air possible should be included in a refuge station regardless of the number of miners seeking refuge. The more air included, the longer the occupants will be able to survive.

The ideal location is a long untimbered drift with an upgrade and with air and water pipes installed. The ideal location may not be available and the best of those available must be chosen. Consideration must also be given to ground conditions. It is of no avail to save oneself from toxic gases, only to be killed by a fall of rock in a refuge station.

Once an area has been chosen, the first step should be to short-circuit the ventilation to keep noxious gases from entering the area. It may be necessary to open or destroy doors or stoppings, turn off fans, tear down ducting, close doors or any number of other things. A refuge station loses its value if it becomes contaminated by a dangerous atmosphere.

Once the ventilation has been short-circuited, a temporary barricade should be built as quickly as possible. When it has been built, more time will be available to improve the airtightness or to move back and erect a more substantial permanent barricade.

Many things can be used to build a barricade. The best of the materials available should be used. Miners have always been noted for their ability to improvise and make the material available do the best possible job. The construction of a barricade could well be the most important improvisation job the miner has ever done.

Two light plank walls can be built and sealed with mud packed between them. Ventilation ducting can be nailed to a structure made of scrap wood. Clothing, waste rags, powder boxes, brattice cloth, pieces of plywood, cement blocks, bags filled with muck, polythene sheets, conveyor belting and pieces of machinery can all be put to use. Mud out of ditches makes good packing in corners, as does paper soaked in water or heavy grease, or mixed with sand. Anything and everything available should be put to use. The next time you have lunch with a group of friends underground, try and think of things that could be used to make an airtight barricade. The important thing is to build a seal as quickly as possible and to make it as airtight as possible.

When the area to be sealed has been chosen, during and after building the seal, a compressed air valve, if available in the area, should be slightly cracked. A cracked air valve inside the sealed-off area will create a slightly higher pressure inside the refuge station. If the pressure inside the station is higher than outside, any leakage through the seal will be outward and dangerous gases will not enter.

Once the seal has been built, the same rules of discipline and conservation of life-sustaining supplies should be observed as when a permanent refuge station is used.

The improvised seal should only be opened by mine rescue personnel, regardless of how long it may take. A temporary seal should be regularly checked and maintained as necessary.

SUMMARY

When miners become aware of a mine fire, explosion or other emergency they must:

GET OUT OF THE MINE
OR
SEEK A REFUGE STATION.

They should first attempt to get out of the mine by normal travel routes. If this is not possible they should then use the secondary or emergency escape route.

In attempting to leave the mine, miners should:

- Travel quickly but safely.
- Travel in groups, keeping in visual or physical contact with each other.
- Make mental notes of conditions encountered.
- Use telephones where available, to learn all information possible and to report their whereabouts, but do not interrupt conversations in progress.
- Select one man as group leader and follow his directions.
- Use self-rescuers immediately on becoming aware of the emergency.
- Follow the mine's planned evacuation procedure if reasonably safe to do so.
- When out of the mine, make a detailed report to the proper authority about the conditions they encountered.

They should not:

- Venture into smoke without self-rescue breathing apparatus.
- Change ventilation without authorization, except to protect their lives.
- Take unnecessary chances or travel along dangerous routes.
- Panic or cause others to panic.
- Overload telephone circuits or interrupt conversations taking place.
- Leave the mine assembly area without authorization.
- Speak to the news media about their experience, as the families of trapped miners could be caused undue anxiety.

If escape from the mine is not possible then refuge should be sought in either a permanent or improvised refuge station.

When sealed in a refuge station occupants should not:

- Unseal the station except to admit additional survivors or unless told to do so by mine rescue personnel.
- Move about or exert any more effort than is necessary.
- Panic or cause others to panic.
- Waste supplies necessary for life, such as oxygen, food and water.
- Lie on the floor where carbon dioxide may accumulate.
- Dispute or argue with the directions of the group leader.
- Smoke.

They should:

- Select a group leader.
- Keep calm and relaxed.
- Conserve oxygen, water, food and light.
- Have someone move about occasionally to mix the air.
- Take care of injured or irrational occupants and restrain them if necessary.
- Check the seal of the station regularly to ensure it is not leaking.
- Crack an air line if available.
- Be prepared for a long wait for rescue.

At the time of a mine emergency a person with the basic knowledge contained in this manual, aware of the mine's emergency procedures, and who acts in a calm, rational manner, has an excellent chance of surviving. USE YOUR HEAD, ACT QUICKLY AND DO NOT PANIC.

CHAPTER 10

ELECTRICAL SAFETY

TRAINING OBJECTIVES

A variety of electrical equipment, ranging from small tools and appliances to large electrically powered machinery, is in widespread use on every mining property. The objectives of this chapter are to familiarize rescue trainees with common electrical hazards and how to cope with injuries caused by electric shocks.

Students must understand:

- **The terms "insulator", "conductor" and "semiconductor".**
- **The hazards of faulty electrical equipment.**
- **Voltage gradient or potential difference.**
  - step potential.
  - touch potential.
- **The nature of injuries caused by electric shocks.**
  - cardiac arrest.
  - ventricular fibrillation.
  - breathing paralysis.
  - electrical burns.

INTRODUCTION

The widespread use of electric power, carried by a vast network of energized wires, has resulted in many injuries due to electric shock, usually as a result of carelessness. Generally, they occur when medical aid is not readily available and first aid must be administered quickly in order to save life.

Many factors influence the severity of electrical injuries. Although high voltages and amperages are dangerous, it must never be forgotten that contact with low voltages can also be fatal. Moisture from perspiration or precipitation provides a better contact and increases the severity of the injury, whereas partial insulation by dry clothing lessens the effect. Very often falls from poles follow electric shock and produce further injury, frequently very severe.

ELECTRICITY: SOME BASIC FACTS

Remember: **Electricity always seeks the easiest path to the ground**. This is true regardless of whether it comes from a household lighting circuit, a high power transmission line, or lightning.

If a person touches two energized wires or touches an energized wire and the ground at the same time, they will become part of an electrical circuit, and may be killed or injured.

ELECTRICAL INSTALLATIONS

Electricity is generated by power plants at voltages ranging from 2300 to 20 000 volts. This voltage is stepped up for efficient transmission over long distances to substations near the load centres. Some transmission lines operate as low as 60 000 volts, others as high as 500 000 volts.

At the substations, voltage is reduced and power is sent through distribution lines to industrial, commercial and residential customers.

COMMON ELECTRICAL TERMS

Some words frequently used in connection with electricity are "voltage", "current" and "resistance".

Voltage can be likened to water pressure. It is the force that causes the flow of electricity.

Current can be compared to the rate of flow of water in a pipe.

Resistance is similar to the effect of friction on the flow of water in a pipe (water flows more freely in a large pipe than in a small one). Different materials have different resistances to the flow of electricity. Very high resistance materials are called **insulators**, while the low-resistance materials are called **conductors**.

In an electrical system, the force or pressure is measured in volts and the current flow in amperes (amps). Resistance is measured in ohms.

INSULATORS, CONDUCTORS AND SEMICONDUCTORS

All materials conduct electricity to some degree. Materials classified as "insulators" conduct electricity in such small quantities it cannot normally be detected. On the other hand, materials classified as "conductors" conduct electricity readily in large amounts. To cite two examples: glass is an insulator; metal is a conductor.

Some other materials are classified as "semiconductors". These include wood, earth and rubber tires. Depending on conditions, such as moisture content and contaminants, semiconductors can conduct large amounts of electricity.

ELECTRICAL HAZARDS

COMBUSTIBLE MATERIALS

Fires involving electrical equipment may result from the presence of combustible materials. For example, most fires that break out in electrical generating plants originate in fuel systems, oil systems, inflammable gaseous atmospheres or combustible buildings and contents.

FAULTY ELECTRICAL EQUIPMENT

Electricity is very safe when it is properly used. However, hazards are created when electrical equipment or wires have become faulty due to:

- Wear or other deterioration.
- Improper installation.
- Inadequate maintenance.
- Improper use.
- Damage or breakage.

Any one of these factors may cause arcing or overheating of electrical equipment – the two conditions that cause the majority of electrical fires. Consider each of these conditions:

- **Arcing** – An electrical arc is a sudden flash of electricity across the gap between two points not quite in contact. An arc is extremely hot. Arcing is usually associated with a short-circuit or a current interruption at a switch point or loose terminal. It may ignite combustible material close by, including the insulating material around the conductor. Burning insulation may be thrown into other nearby flammable material, starting a fire.
- **Overheating** – Overloading of electrical conductors and motors accounts for the majority of fires caused by overheating. There is danger when the amount of current exceeds that which conductors and equipment are designed to carry.

LOW VOLTAGE HAZARDS

Most electrically caused fires originate in equipment operating below 750 volts. In the electrical industry, this is referred to as low voltage. Home heating systems and appliances operate at 220 volts or less.

Although the hazard is greater with high voltage installations, it is important for rescue personnel to appreciate the hazards of even relatively low voltages.

VOLTAGE GRADIENT ON THE GROUND SURFACE

Because electricity always seeks the quickest, easiest path to ground, electrical systems use conductive grounding rods to ensure that any stray current is returned to earth safely. These rods are driven 2.5 metres (8 feet) or more into the ground to ensure deep dispersal of the power. However, if electricity is released onto the ground surface, such as when a "live" wire lies on the ground, the electricity will fan out from the point of contact.

There is a rippling effect that can be likened to dropping a pebble into calm water. In the pool of water, the wave created at the point of contact gets smaller as it spreads outward. Similarly, in a "pool" of electricity, the energy is at full system voltage at the point of ground contact, but as you move away from the contact point, the voltage drops progressively. This effect is known as "ground gradient" and understanding how it operates may some day save your life.

STEP POTENTIAL AND TOUCH POTENTIAL

The ground gradient, or voltage drop, creates two problems known as "**step potential**" and "**touch potential**".

Let us assume that a live downed wire is touching the ground and has created a "pool" of electricity. If you stand with one foot near the point of ground contact (at x voltage) and your other foot a step away (at y voltage), the difference in voltage will cause electricity to flow through your body. This effect is referred to as "step potential" (Figure 10-1).

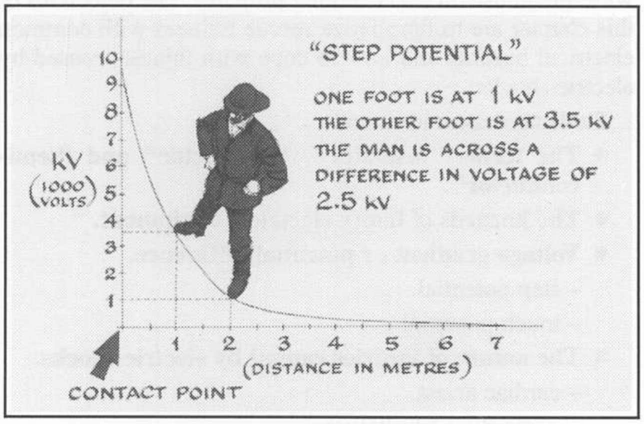


Figure 10-1. Step potential.

Similarly, electricity will flow through your body if you touch an energized source with your hand, while your feet are at some distance from the source. The difference in voltage in this case is referred to as "touch potential" (Figure 10-2).

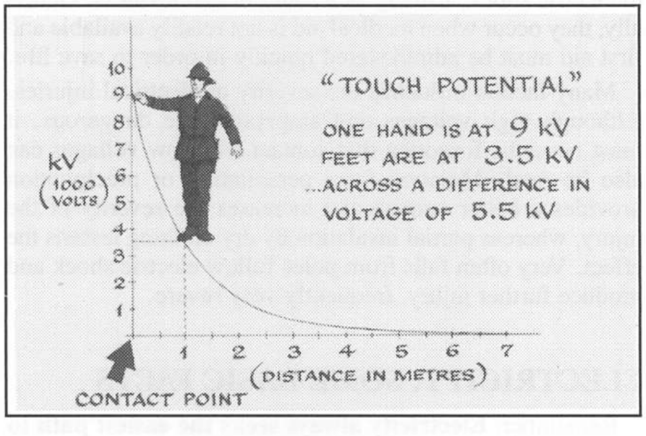


Figure 10-2. Touch potential.

INJURIES CAUSED BY ELECTRIC SHOCKS

EFFECTS OF ELECTRICITY ON THE BODY

The effect of electricity on the body is dependent on the amount of current and the length of time the body is exposed to it. The higher the current, the less time a person can survive the exposure.

The path of electricity through the body is also critical. For example, current passing through the heart or brain is more life-threatening than current passing through the fingers. It takes approximately 1000 milliamps (1 amp) of current to run a 100-watt light bulb. The effects you can expect from just a fraction of this current for a few seconds are illustrated in Figure 10-3. A small amperage for a few seconds can be fatal.

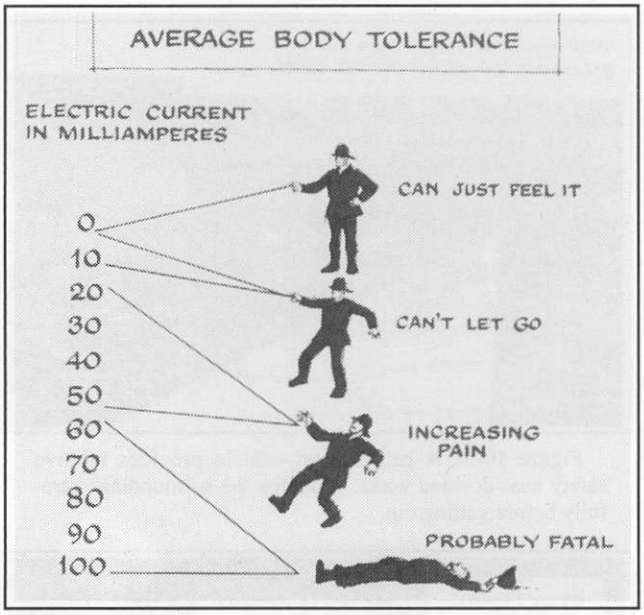


Figure 10-3. Average body tolerance; the response to increasing current.

It is the current (amperage) that kills or injures. But the voltage, which pushes the current through the body, also has an important effect. Persons exposed to household voltages may suffer a muscle spasm and be locked-on to the electrical source until the current is turned off, or until they are dragged clear by the weight of their body falling clear of the contact. Relatively long periods of contact with low voltage current are the cause of many electrical fatalities in the home.

At very high voltages (on power lines, for example) the victim is often quickly blown clear of the circuit. This results in less internal damage, such as heart failure, but terrible surface burns where the current enters and leaves the body. Exposure to a large electric arc can result in injury from the intense heat or from ultraviolet rays which can cause serious eye damage.

In addition to the factors outlined above, the effect of electricity on the body depends on: the condition of the skin; the area of skin exposed to the electrical source; and the pressure of the body against the source. The severity of the shock will be increased if the point of skin contact is moist or broken.

Any victim of electrical shock must be examined for the following effects on the body (Figure 10-4):

- Contraction of the chest muscles, causing breathing difficulty and unconsciousness.
- Temporary paralysis of the respiratory centre, causing breathing failure.
- Ventricular fibrillation of the heart (usually resulting from lower voltages).
- Burns to tissue at the entrance and exit points (usually resulting from higher voltages).
- Fractures caused by muscle spasm.

Remember that **the danger must be removed** before any treatment is given to the patient. Sometimes the circuit can be turned off; sometimes it cannot. Only at household voltage levels can the victim be removed from a live circuit using common insulating materials. **At high voltages, special tools must be used.**

HOW TO COPE WITH ELECTRICALLY CAUSED INJURIES

First aid procedures for victims of electric shock are summarized as follows:

Electrical Injuries	**Action to be Taken by Emergency Personnel**
Cardiac arrest. Heart action may stop if control centres of the heart are paralyzed.	Start cardiopulmonary resuscitation immediately.
Ventricular fibrillation. This condition is more likely to be caused by a shock of relatively low voltage. The heart muscles lose their normal rhythm. They quiver and throw the heart into spasm.	Start cardiopulmonary resuscitation immediately.
Breathing stops. If a particular nerve centre in the brain is paralyzed, breathing will stop.	Start artificial respiration immediately and monitor the pulse to ensure that blood is circulating. If a flow of oxygen to the lungs can be maintained by artificial respiration until the paralysis wears off, normal breathing will usually be restored.
Electrical burns. Current passing through the body generates heat and may cause blisters on the skin. If the current is strong enough, it may destroy body tissue and result in severe electrical burns. The outward appearance of electrical burns may not seem serious, but they are often very deep and are slow to heal.	Standard emergency procedure for burns. Prompt medical attention is required to prevent infection. Examine the victim for an *exit* burn as well as an *entry* burn.

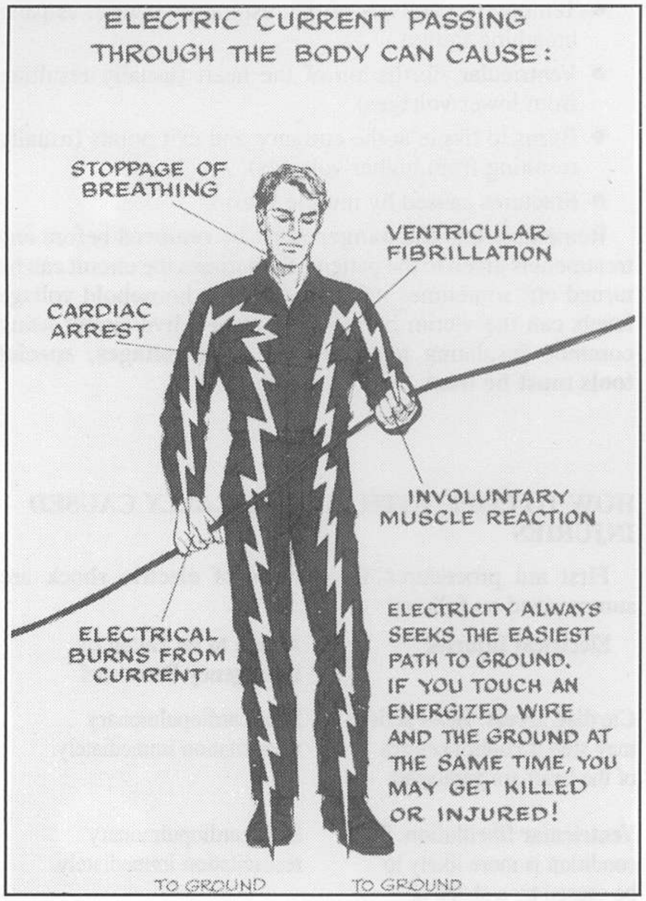


Figure 10-4. The effects of electric current passing through the body.

HOW TO DEAL WITH BROKEN WIRES

Electrical distribution wires may be broken by storms, ice or as the result of vehicles striking power poles.

If, during your work, you come across abnormal situations such as broken or fallen wires, do not expose yourself to needless risks while trying to eliminate the danger. Always assume that the wires are energized and capable of killing people. You should inform the electrical supervisor as soon as practical. Qualified electricians will be sent to remedy the situation.

Needless to say it is your responsibility to minimize the danger to yourself and others until expert help arrives; safe procedures are as follows:

(1) If you arrived on the scene by vehicle, make sure you are parked well away from the fallen wires before getting out. If it is dark, use a flashlight to examine the surroundings carefully from the car or truck window. If you are parked over or near the fallen wires, move your vehicle well out of harm's way (Figure 10-5).

(2) Now look around for the exact location of all wire ends. They may be on the ground or in the air. If a live wire touches a car or truck, or any other metal object, that object will be capable of killing people. So will a pool of water if a live wire has fallen into it. You must prevent bystanders from making any contact with energized objects (Figure 10-6).

(3) Place a guard around the danger zone and call Hydro for help.

(4) Keep people well away from the broken or sagging wires or other electrically charged objects. Live wires in contact with objects on the ground may burn through, and one end may then curl up or roll along the ground, causing injury (Figure 10-7).

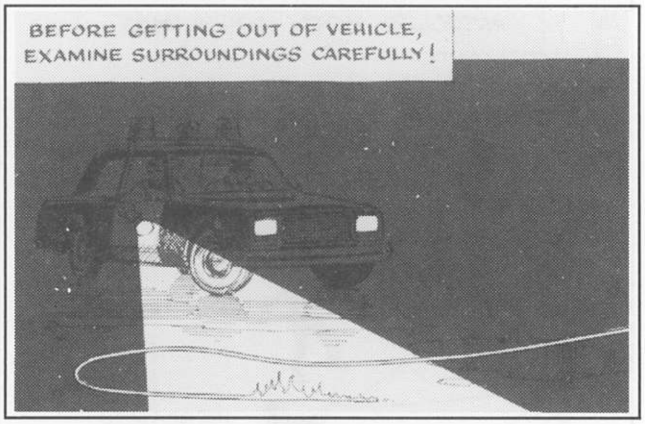


Figure 10-5. A rubber-tired vehicle provides relative safety near downed wires. Examine the surroundings carefully before getting out.

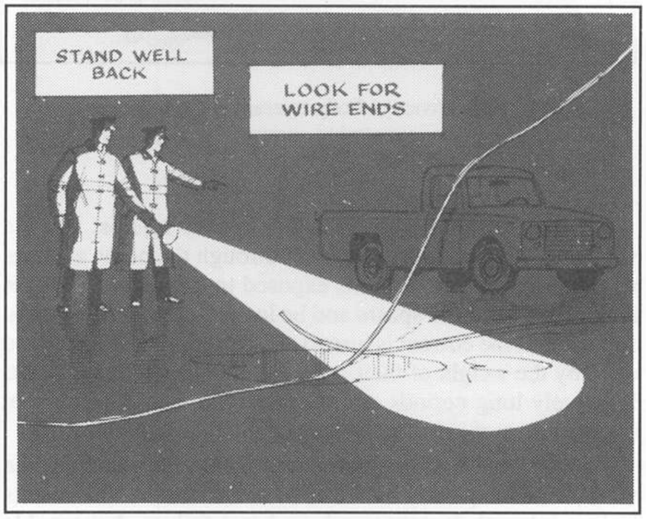


Figure 10-6. Stand well back and look for loose ends of wires.

Figure 10-7. Unbroken wires may burn through and recoil.

If a wire has fallen on a metal fence or any other metal object, electricity may be conducted to other places and the ground itself may be energized to a dangerous level near the fallen wire.

(5) **Do not move fallen wires if you do not have proper training and equipment.**

(6) If you have been trained in the proper procedures, and have specialized equipment on hand, you may move wires, but only when it is necessary to save human life. Otherwise, wait until Hydro crews arrive.

Years ago, it may have been safe to move a live downed wire with a dry piece of wood, rope or some other handy device, but that time is long gone. Today, power lines carry much higher voltages and should only be handled by a qualified electrician using specially designed epoxy glass tools of known insulation value. Safe procedures in some typical situations are summarized below.

Emergency Situation	**Action to be Taken by Emergency Personnel**
A fallen wire lies under a vehicle, with one or more people inside.	Do not touch any part of the vehicle. You could be electrocuted, even if you are wearing rubber gloves.
The driver is unhurt and can move the vehicle (Figure 10-8).	Instruct the driver to move the car clear of the wire, and clear of any pools of water which may be energized by the live wire. Make sure you are not in a position to be injured if the wire springs up after being released when the vehicle moves. Also make sure no one else is standing in a dangerous location.
A fallen wire lies across a vehicle with one or more people inside.	Instruct both driver and passengers to stay where they are until electrical crews arrive.
If the driver is injured and cannot move his vehicle.	Instruct the driver to stay in the vehicle until electrical crews arrive.

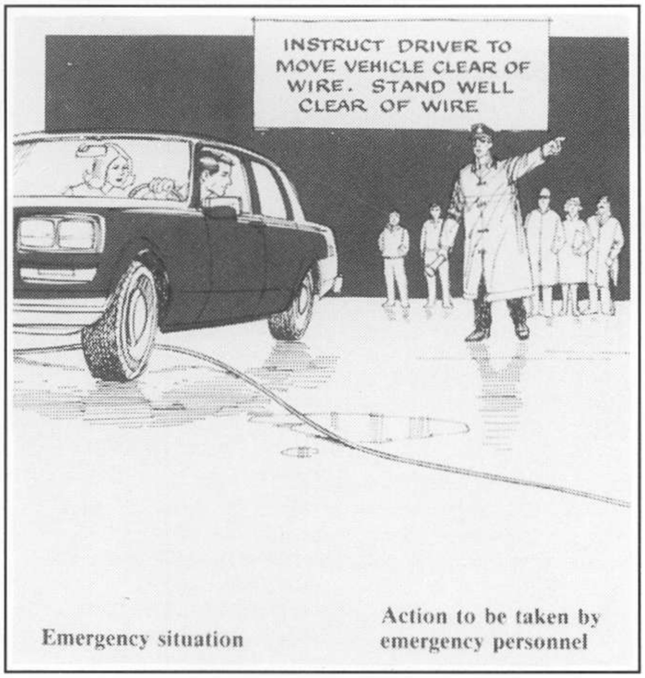


Figure 10-8. Instruct the driver to move vehicle clear of downed wire. Stand well clear of the wire yourself.

ELECTRICAL LOCK-OUTS

Before beginning a rescue operation, electrical lock-outs must be done wherever there is a possibility of electrical equipment starting, energizing or moving and thus creating a dangerous situation.

- All lock-outs on the high voltage system must be done by an electrician.
- Rescue crews are responsible for ensuring that the equipment is locked-out and tagged in a safe condition before work begins.
- No tag or lock is to be removed except by its owner or, in extreme cases (where the owner of the tag or lock is not available), only after a thorough check has been made by the rescue team captain.
- If rescue workers are in doubt as to what should be locked-out electrically, an electrical supervisor must be contacted to confirm what needs to be isolated to ensure personal safety.

CHAPTER 11

RESCUE RIGGING

TRAINING OBJECTIVES

The primary objective of mine rescue work is the safe recovery of accident victims, often from dangerous and inaccessible places. This will frequently require the use of ropes and harnesses to allow rescue workers to reach the injured and to raise or lower them to safety. This chapter will provide a working knowledge of the following:

- Ropes, webbing, carabiners, lanyards and related equipment, and their uses in rescue work.
- How to tie a number of knots used in rescue work.
- The use of harnesses and how to secure a patient to a rescue stretcher.
- How to rappel safely from one elevation to another.
- How to raise or lower a patient from one elevation to another.
- How to set up a safe anchor system.

TYPES OF ROPE

Rope is used for rescue and recovery work and for climbing. Ability to use rope properly is important both underground and on surface. Bringing an injured patient out of a stope is no different from raising an accident victim up over a bench in an open-pit mine or over any natural obstacle on surface. Rope is made of natural or synthetic fibres spun into yarn then twisted into strands. Three or more strands are twisted to form a rope. The individual strands are usually twisted to the left, then twisted together to the right to form the rope. This counter twisting gives the rope a "set" and prevents unwinding.

NATURAL FIBRE

Natural fibres used in rope are sisal and manila. Sisal ropes are cheaper and have less strength than manila rope. Manila rope is strong and will withstand severe use if properly cared for. Synthetic ropes have almost entirely replaced natural ropes for mine rescue work. Synthetics are resistant to mildew and rot, and stronger for equivalent diameters.

SYNTHETICS

Nylon, terylene, propylene and dacron are synthetic fibres used in rope. Nylon ropes are most commonly used for mine rescue work. They are resistant to abrasion, strong and easy to handle, and have about twice the strength of equivalent manila rope. A disadvantage of nylon is its stretch. Other synthetics do not stretch as much as nylon, but they are not as strong.

KERNMANTLE

Kernmantle rope is not twisted. The "kern" or interior core is made of continuous fibres braided in units. The mantle is woven around the outside. Edelrid is the brand of kernmantle rope used in British Columbia. It is expensive but exceptionally strong for its diameter.

BREAKING STRENGTH

The strength of rope depends on its diameter, the material it is made of and its condition. Generally nylon rope is twice as strong as the equivalent manila. A kink or knot in a rope reduces its strength; only a straight length of rope, with no knots, can be rated at 100 per cent of its breaking strength. Mildew, dry rot or chemical damage can considerably reduce the strength of a rope with no visible sign of deterioration. Proper care of rope is essential to maintain the rated strength. Never take a chance by using rope of questionable condition.

Table 11-1 shows the approximate breaking strength of nylon rope of various diameters.

TABLE 11-1
APPROXIMATE BREAKING STRENGTH
2-IN-1 NYLON ROPES

Rope Diameter		Approximate Breaking Strength (unknotted)	
in	cm	lb	kg
1/4	0.6	2200	1000
5/16	0.8	3400	1550
3/8	1.0	4800	2175
7/16	1.1	6500	2950
1/2	1.3	8300	3750
9/16	1.4	11200	5075
5/8	1.6	14500	6575
3/4	1.9	18000	8150
13/16	2.1	22000	10000
7/8	2.2	26500	12000
1	2.5	31300	14200

SAFE WORKING LOAD (SWL)

The safe working load (SWL) for rope uses a factor of five as a safety margin. The minimum breaking strength of ropes is established by testing. If the minimum breaking strength is known, the formula for calculating the SWL is:

$$\text{SWL} = \frac{\text{MINIMUM BREAKING STRENGTH}}{5}$$

A rule of thumb for determining the SWL, not as accurate, but erring on the side of safety is:
Convert the size to 1/8ths of an inch and square the result, then multiply by these factors:

Nylon	× 60
Polyester	× 60
Polypropylene	× 40
Polyethylene	× 35
Manila	× 20

For $^{1}/_{2}''$ manila $SWL = \frac{2650}{5} = 530$ lb (formula).

$^{1}/_{2}'' = 4/8$: $4^2 = 16$: $16 \times 20 = 320$ lb (rule of thumb).

For $^{1}/_{2}''$ nylon $SWL = \frac{8300}{5} = 1660$ lb (formula).

$^{1}/_{2}'' = 4/8$: $4^2 = 16$: $16 \times 60 = 960$ lb (rule of thumb).

Take care to ensure that ropes will not be overloaded in rescue and recovery operations. The rule-of-thumb formula increases the margin of safety and is easy to remember. It should be used.

Kermantle rope is stronger than regular rope due to the continuous filament construction. Edelrid is two to three times stronger then nylon rope of equivalent diameter.

CARE OF ROPES

Manila and other hard-fibre ropes should be "worked" before using. Working the rope by pulling, twisting and stretching it will make it more pliable and easier to handle. Manila rope should be wiped with a coarse cloth several times to remove the small fibre slivers. The ends of a rope should be whipped or back spliced. Synthetic ropes can be melted at the ends to stop unravelling. Heat-shrink tubing can also provide a neat end to a rope.

- Make sure rope is dry before coiling.
- Coil carefully, avoid twists and kinks.
- Hang coiled ropes or store neatly.
- Avoid unnecessary exposure to sunlight for synthetics.
- Keep all ropes away from chemicals.
- Inspect the entire length of rope before using it, even if new.
- Avoid dragging ropes over sharp edges, each other or the ground.
- Use the proper rope diameter in pulley blocks.

WEBBING

Two types of webbing are used for rescue work. These are listed below.

	Breaking Strength
Tube – Edelrid – 25 mm	1800 kg
– 50 mm	
Tape – 25 mm	1500 kg
– 45 mm	2200 kg

Various sizes and lengths of webbing can be used for different applications. Each has a purpose such as anchor points, body harnesses, stretcher-lifting devices and securing patients.

To make up webbing straps, use a ring bend knot.

CARABINERS

Carabiners are used by rescuer for clipping equipment to a rope or sling, or onto the rescuer's belt. They are a steel loop, similar to a link in a chain, but generally D-shaped, with a hinged gate on the shorter side which can be closed to secure the equipment in place (Plate 11-1). Locking carabiners, with a threaded sleeve that screws over the open end of the gate to prevent it from opening during use, are commonly used in rescue work. Using a carabiner allows items of equipment to be attached and detached quickly and easily.

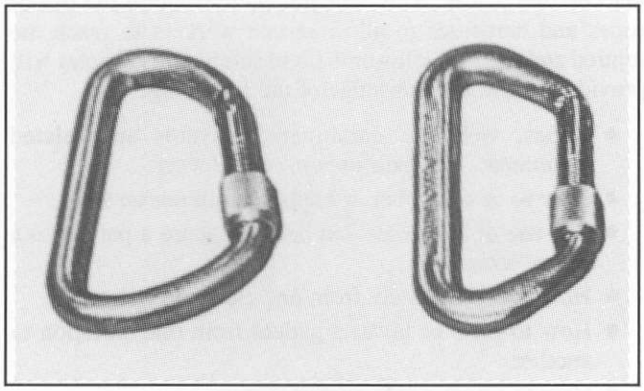


Plate 11-1. Steel carabiners used in rescue work.

Carabiners are invaluable for many purposes; proper handling will become second nature if good habits are developed from the outset. Although it is good practice to make sure that all carabiners are locked prior to starting a rescue operation, it is tedious and a waste of time to unlock and lock them each time a piece of equipment is clipped in. Do not close the lock until all the items to be carried have been hooked up. The correct procedure for attaching a carabiner to a sling is:

Step 1 – Hold the carabiner with the solid back angled across your palm and fingers and use your thumb to open the gate (Plate 11-2).

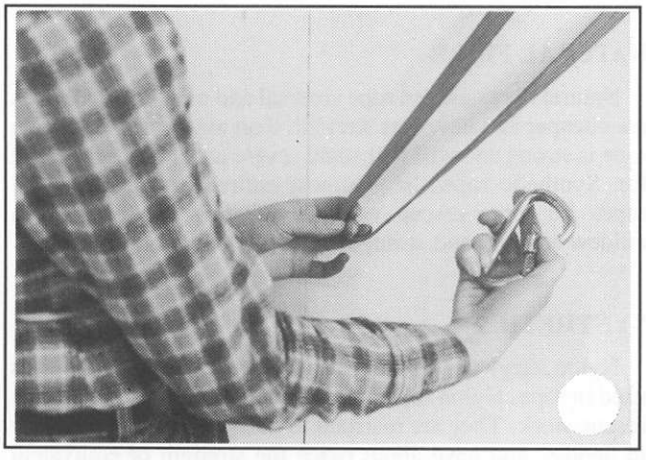


Plate 11-2. Attaching a carabiner to a sling. Step 1: Hold the carabiner across the palm and fingers. Open the gate with the thumb.

Step 2 – Twist your wrist so that the carabiner hooks over and down around the sling (Plate 11-3).

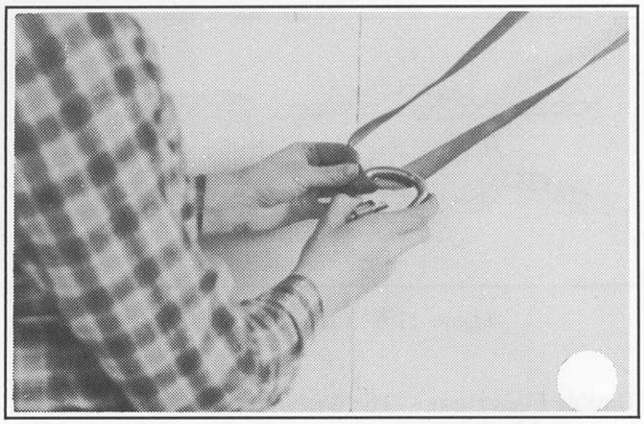


Plate 11-3. Attaching a carabiner to a sling. Step 2: Hook the carabiner over and down around the sling.

Step 3 – Close the gate and turn the carabiner end over end so that the gate is facing downwards, away from any pressure that might open it (Plate 11-4).

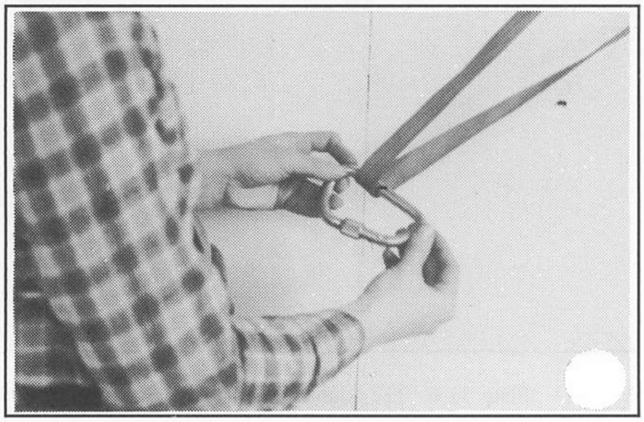


Plate 11-4. Attaching a carabiner to a sling. Step 3: Close the gate and turn the carabiner end over end.

Step 4 – With the sling at the hinge end there will be ample room to clip in other pieces of equipment (Plate 11-5).

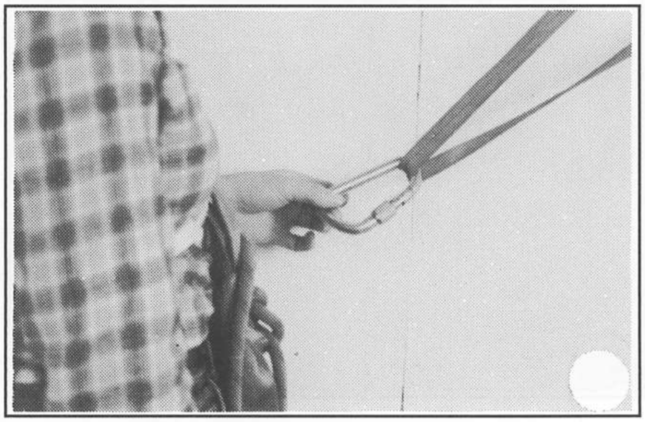


Plate 11-5. Attaching a carabiner to a sling. Step 4: Place the sling at the hinge end.

When adding items to a carabiner that already has something in it, hold it with the things already attached at the hinged end, near your wrist, leaving the open end free to accept whatever you wish to clip on.

As with all other equipment, treat carabiners with care as they can be damaged if they are dropped or grit works into the hinge or sleeve. Do not throw them from one person to another; if the "receiver" misses the pass the carabiner may be damaged or, working on a steep slope, very likely lost. It is best to pass small pieces of eqipment to another crew member by hand, feeling the other person's grip before you let go. If direct contact is impossible due to rough terrain, the crew should be roped together; it is then a simple matter to clip small equipment to the rope, using a carabiner, and slide it down to the next person on the rope.

KNOTS

Knots are used for tying two ropes together, or fastening a rope to some other object. Familiarity with a few terms will be helpful in learning to tie different knots.

A rope has two ends and a middle. There are no particular terms to describe intermediate positions. The end in use is called the "running end". The rest of the rope is called the "standing part". A "bight" or "hitch" (Figure 11-1) is an open loop in the standing part and is a part of many other knots. An "overhand loop" has the running end cross over the standing part. An "underhand loop" has the running end cross under the standing part.

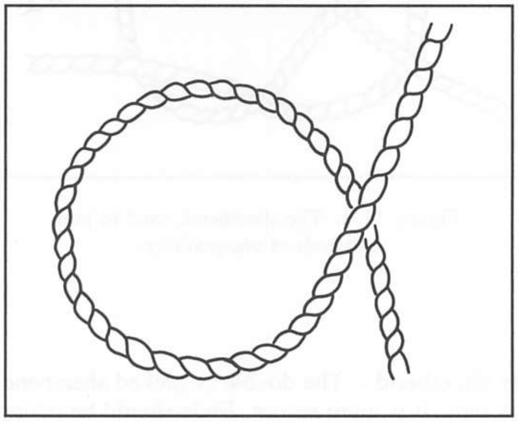


Figure 11-1. The hitch, a part of many other knots.

END KNOTS

End knots are used to temporarily prevent fraying and to stop rope from sliding through a block, hole or other knot.

Overhand Knot – Very simple knot (Figure 11-2).

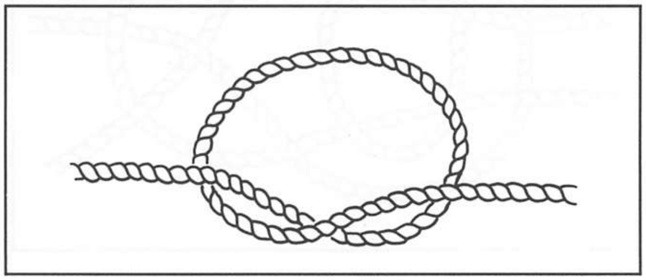


Figure 11-2. The overhand knot.

Figure-of-eight Knot – Larger than overhand knot. When tightened the end projects at a right angle to the standing part (Figure 11-3).

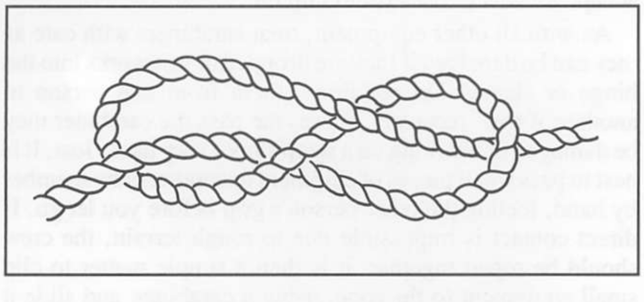


Figure 11-3. The figure-of-eight knot.

Sheetbend – Used to join ropes of different sizes. It is more secure if the ends are whipped. Can also be tied "slippery" with the end tucked through in a bight. Slippery knots are easily undone by pulling the free end. A shoe-tie is a slippery reef knot (Figure 11-4).

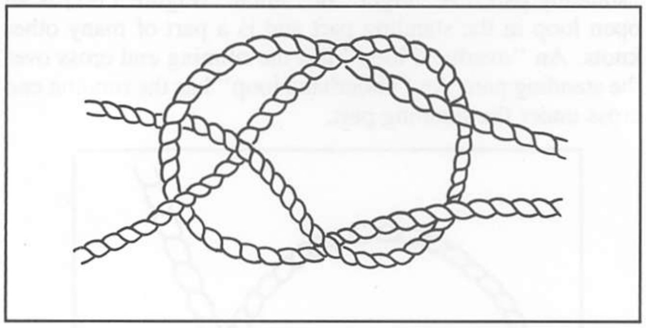


Figure 11-4. The sheetbend, used to join two ends of unequal size.

Double Sheetbend – The double or tucked sheetbend has an extra turn. It is more secure. Ends should be whipped (Figure 11-5).

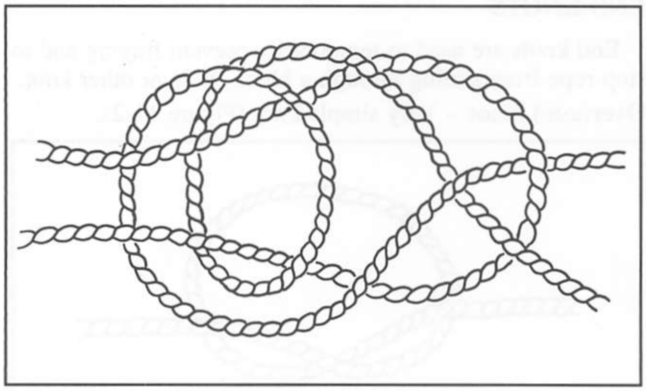


Figure 11-5. The double sheetbend.

Fisherman's Knot – A simple knot for joining two ropes. Can be used with Edelrid climbing rope (Figure 11-6).

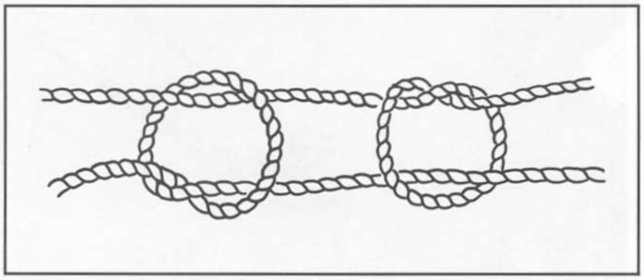


Figure 11-6. The fisherman's knot.

Double Fisherman – The double fisherman is a stronger knot used for joining two rope ends of equal diameter. Two half hitches are made around each rope with the other running end (Plate 11-6).

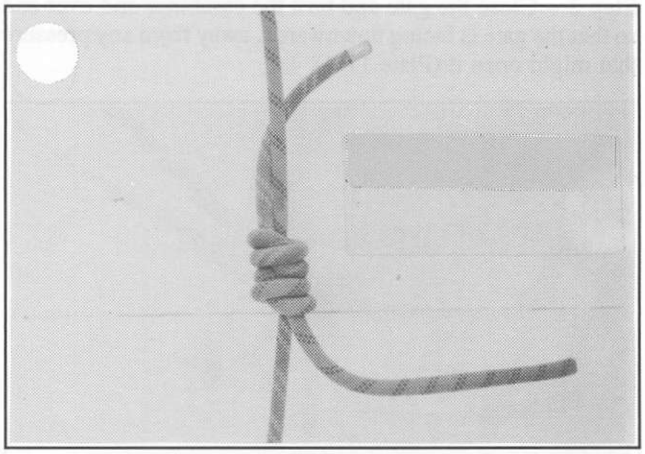


Plate 11-6. The double fisherman's knot.

Ring Bend – The ring bend is the most desirable knot for connecting webbing to webbing (Plate 11-7).

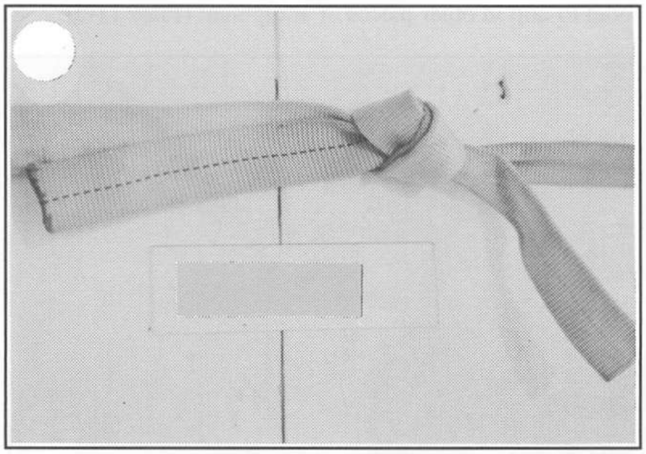


Plate 11-7. The ring bend for joining two pieces of webbing.

HOLDING KNOTS

Clove Hitch – The clove hitch is used for making a line fast to a pole or post. It can be used vertically or horizontally. It can also be tied by slipping loops over the end of a crossmember. It is often used in lashings (Figure 11-7).

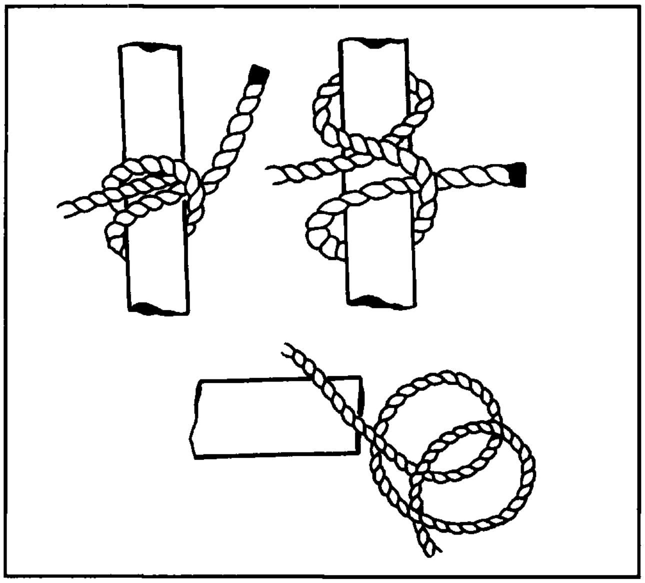


Figure 11-7. The clove hitch, used for making a line fast to a pole or post.

Round Turn and Half Hitch – The half hitch is part of many knots. It will also hold under a steady pull on the standing part. It is used as a stopper knot for bowlines (Figure 11-8).

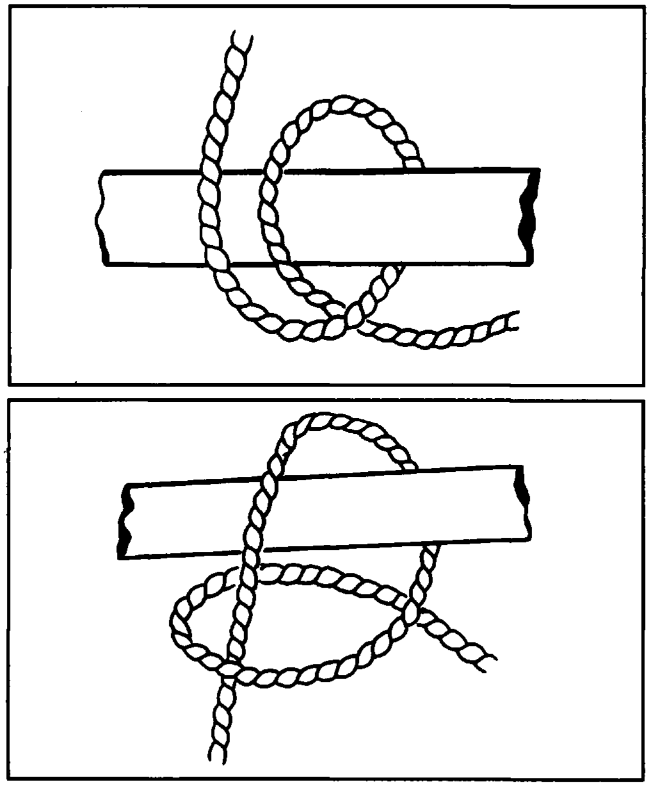


Figure 11-8. The round-turn and the half-hitch.

Round Turn and Two Half Hitches – The round turn and two half hitches is used to secure a rope to a post or pipe. It will take heavy strain without slipping and will not jam (Figure 11-9).

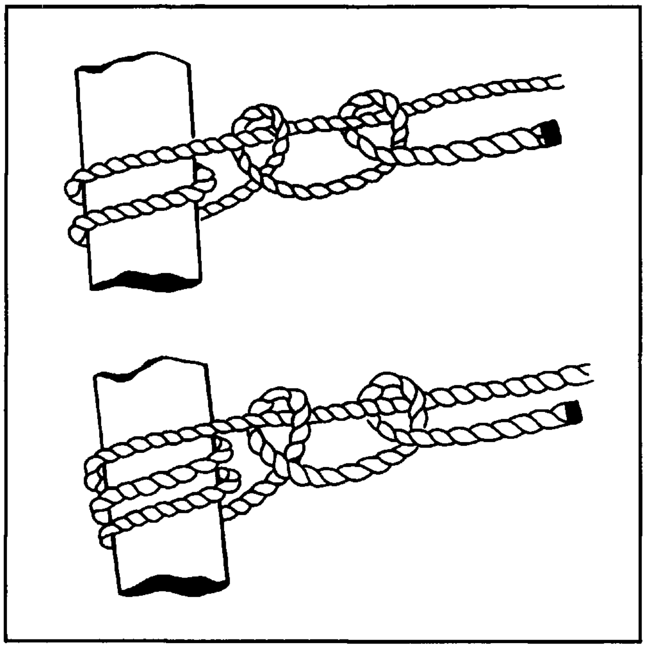


Figure 11-9. The round-turn and two half-hitches.

Timber Hitch – The timber hitch is used to hoist or drag timber or pipes. The half hitch will keep timber or pipe pointing in the direction of pull (Figure 11-10).

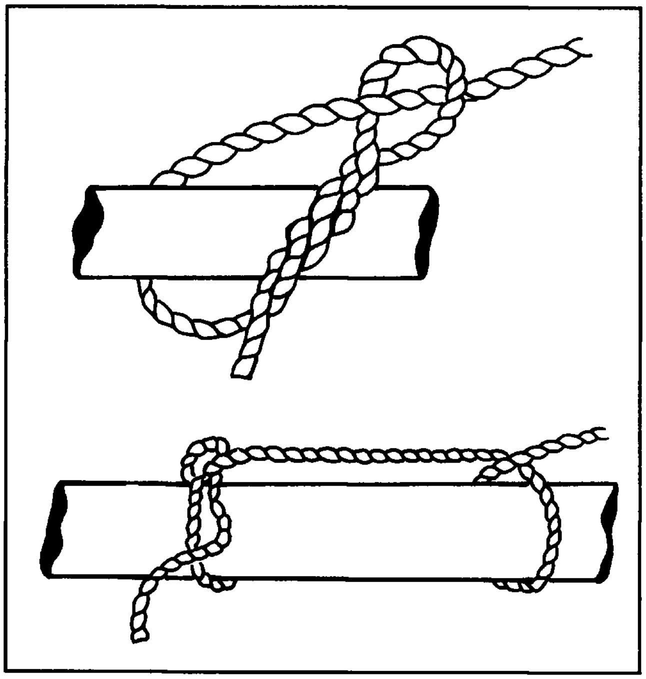


Figure 11-10. The timber hitch.

Bowline – The bowline is very widely used when a loop that will not jam, slip or fail is required. It is simple to tie even with one hand (Figure 11-11).

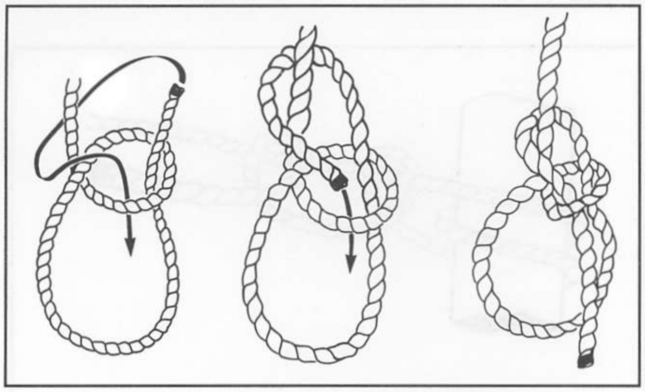


Figure 11-11. The bowline – a loop that will not slip.

Bowline on the Bight – The bowline on the bight can be used to lift an injured man. One loop is under the armpit and the other under the bottom. It can also be used to tie a bowline in the middle of a rope (Figure 11-12).

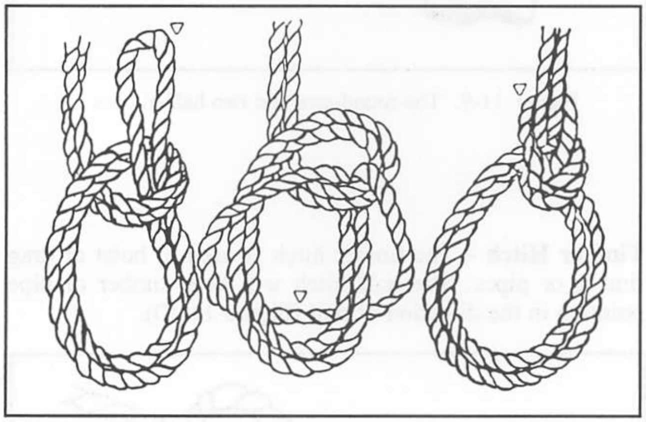


Figure 11-12. The bowline-on-the-bight makes two loops.

Figure-of-eight on a Bight – The figure-of-eight on a bight is used for forming an attachment point within the standing part of a rope, also at the rope's end occasionally (raising or lowering baskets) (Plate 11-8).

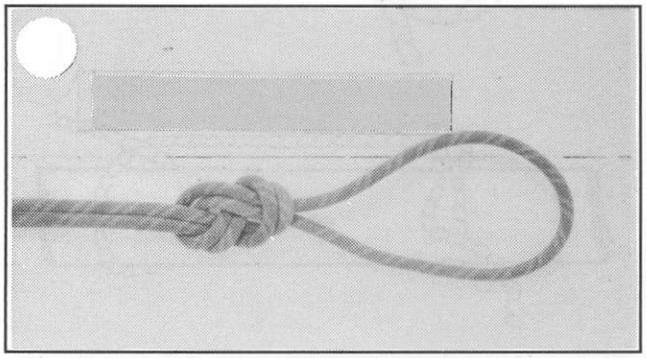


Plate 11-8. The figure-of-eight on a bight.

Butterfly Knot – The butterfly knot forms a single loop that will not slip if tightened. For this reason it is often used as a "middle man's" knot. The butterfly is felt to be the strongest of the "middle man's" knots (Figure 11-13).

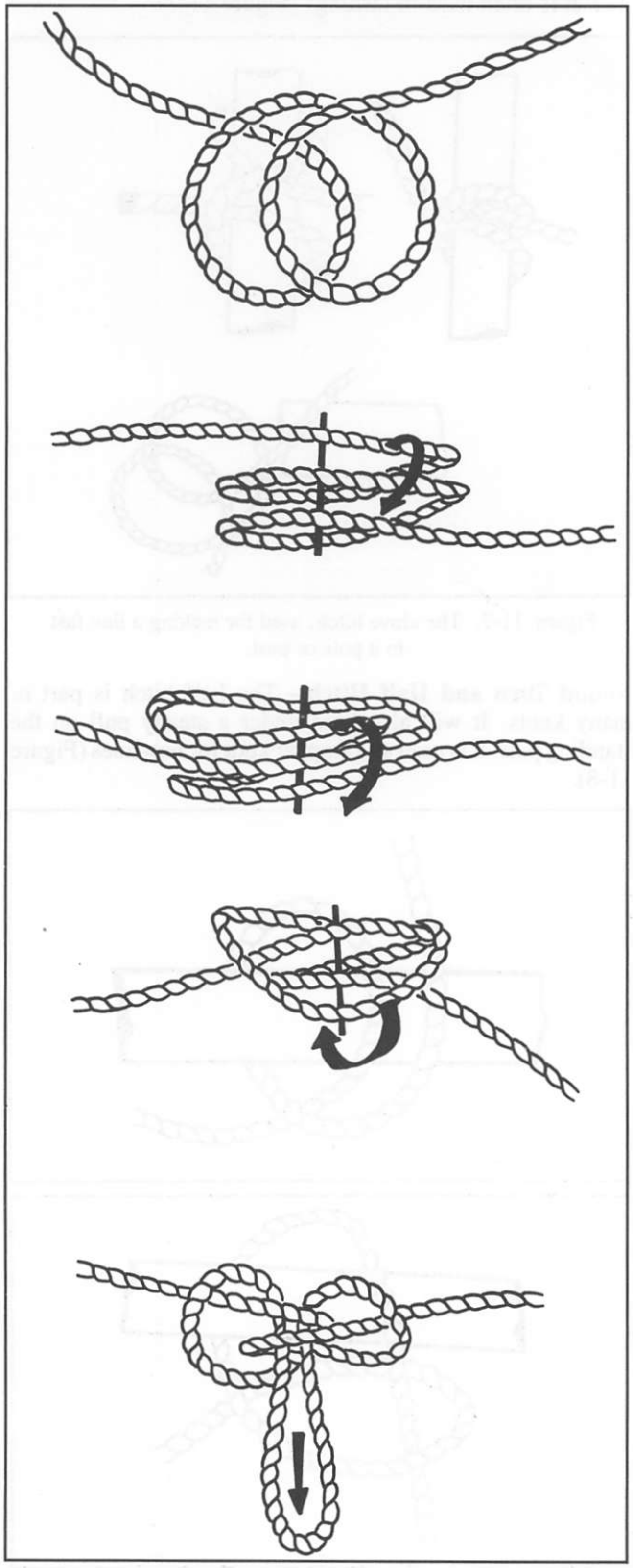


Figure 11-13. The butterfly knot.

Catspaw – The catspaw is used to fasten the middle of a rope to a hook, post or carabiner (Figure 11-14).

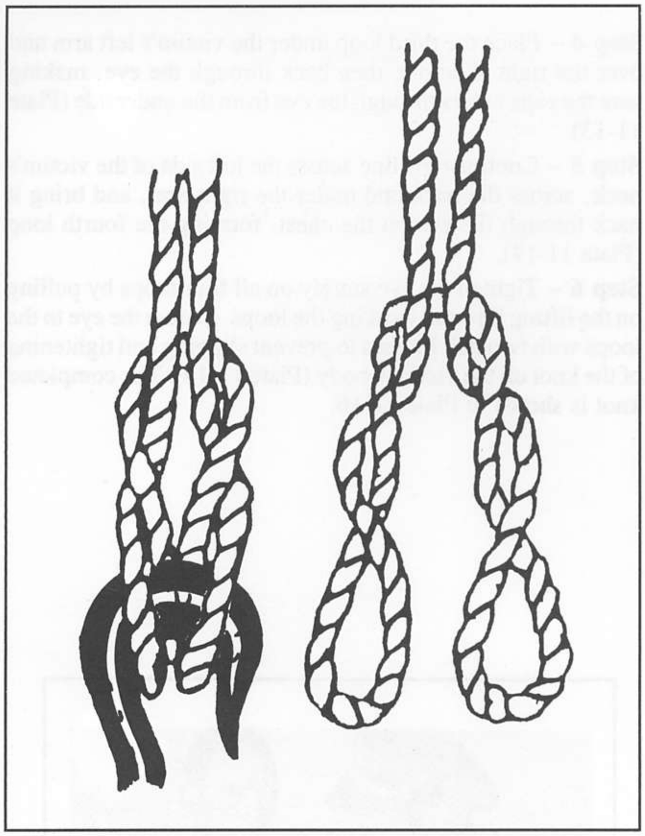


Figure 11-14. The catspaw.

FRICTION KNOTS

Prussik – The prussik is a hitch of lighter cord "usually 7 millimetres around a main line", such that it will slide along the main line when the hitch itself is pushed out, but will grip when its standing part is pulled. It is useful for prussiking and belaying (Plate 11-9).

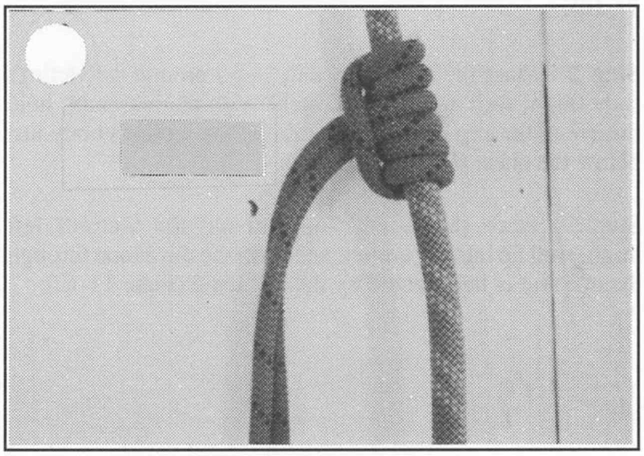


Plate 11-9. The prussik.

Baukman Ratchet – The Baukman ratchet is used as a brake. It is made up by incorporating a prussik tie around a carabiner and the main-line rope (Figure 11-15). It was developed as an alternative to the prussik, which is hard to grip or loosen with cold wet hands. Three wraps around the main-line rope with 7-millimetre kermantle rope are recommended. The maximum load is 1500 kilograms (3300 pounds) depending on the strength of the main line.

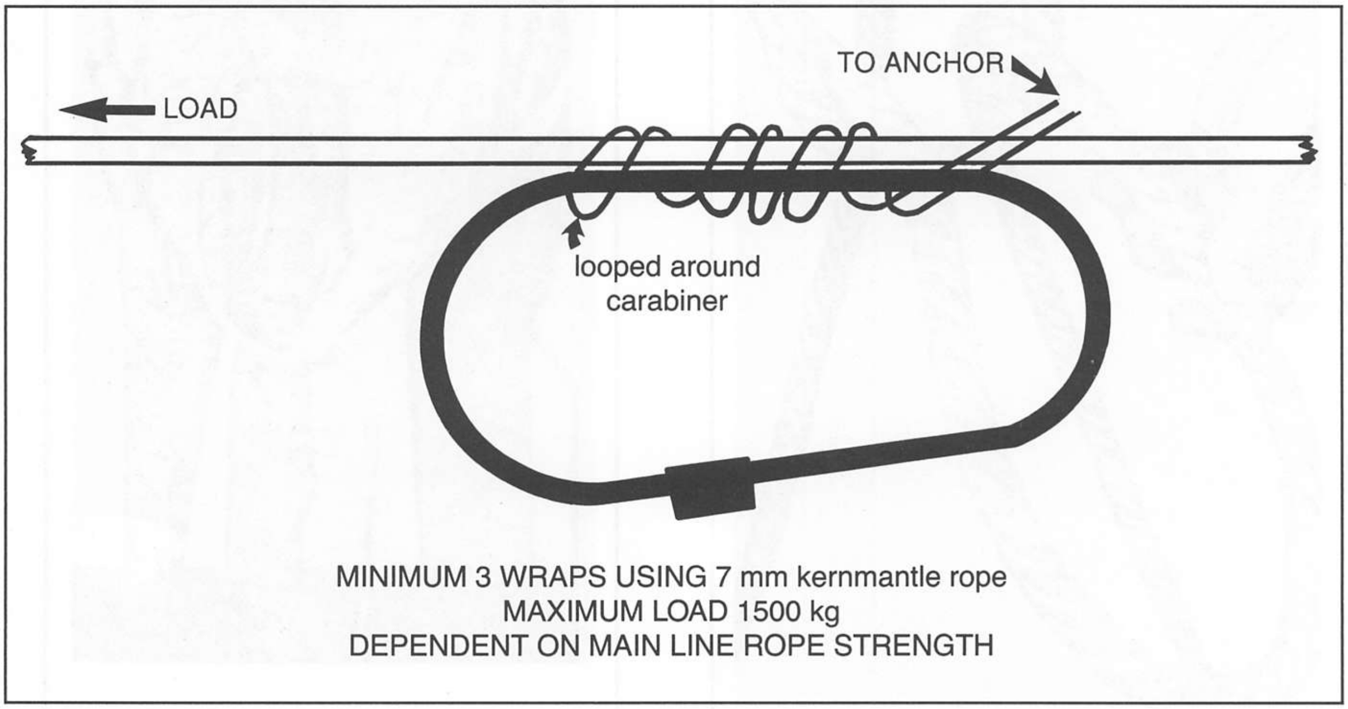


Figure 11-15. The Baukman ratchet.

HARNESSES USED IN RESCUE WORK

BUTTERFLY HARNESS

Step 1 – Measure four double arm lengths of rope across the body to provide enough working line and tie an ordinary slip knot to form the first loop for one of the victim's legs (Plate 11-10).

Step 2 – Place the loop formed in Step 1 around the victim's right thigh, well up into the crotch. With the left hand, hold the eye of the slip knot in the centre of the victim's body just below the chest (Plate 11-11).

Step 3 – Place the second loop around the victim's left thigh, well up into the crotch, and form the third loop through the eye that is held secure by the left hand (Plate 11-12).

Step 4 – Place the third loop under the victim's left arm and over the right shoulder, then back through the eye, making sure the rope enters through the eye from the underside (Plate 11-13).

Step 5 – Continue the line across the left side of the victim's neck, across the back and under the right arm, and bring it back through the eye on the chest, forming the fourth loop (Plate 11-14).

Step 6 – Tighten the eye snugly on all four loops by pulling on the lifting line and working the loops. Secure the eye to the loops with two half hitches to prevent slipping and tightening of the knot on the victim's body (Plate 11-15). The completed knot is shown in Plate 11-16.

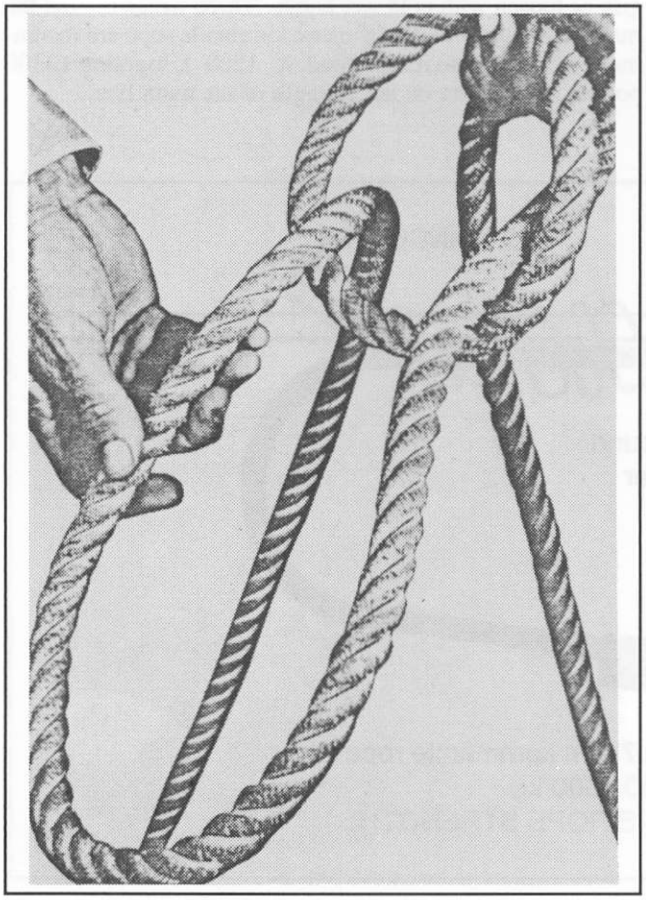


Plate 11-10. Preparing a butterfly harness; Step 1.

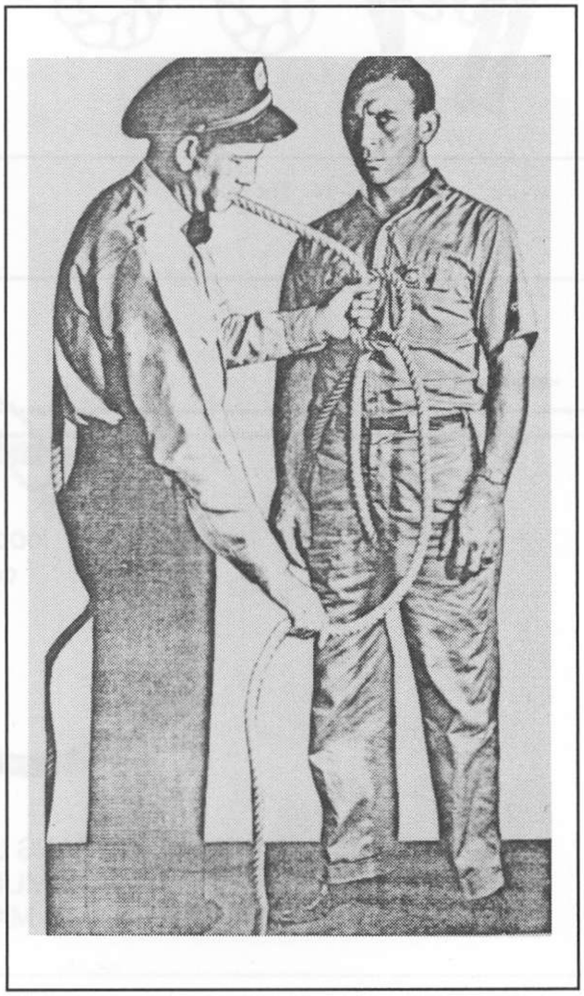


Plate 11-11. Preparing a butterfly harness; Step 2.

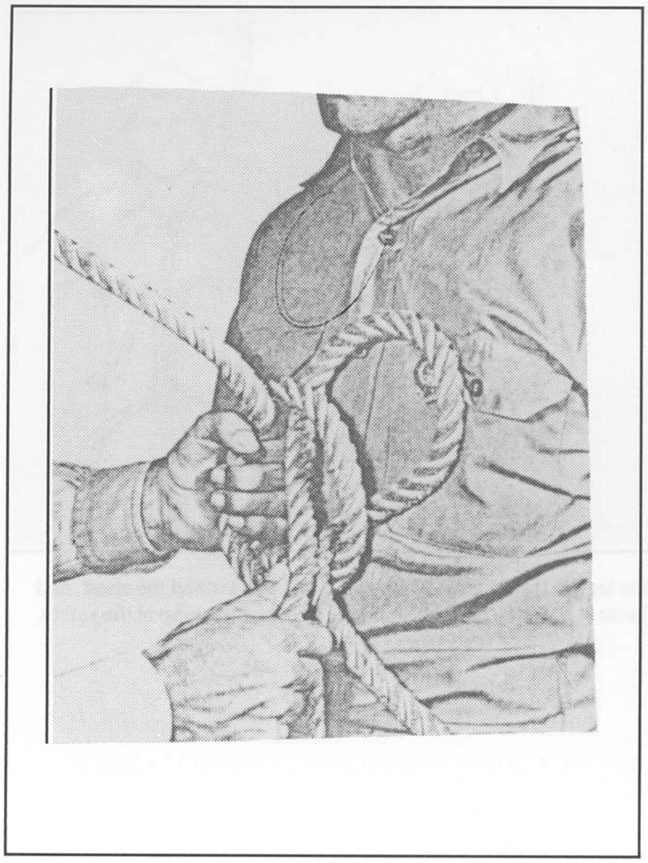


Plate 11-12. Preparing a butterfly harness; Step 3.

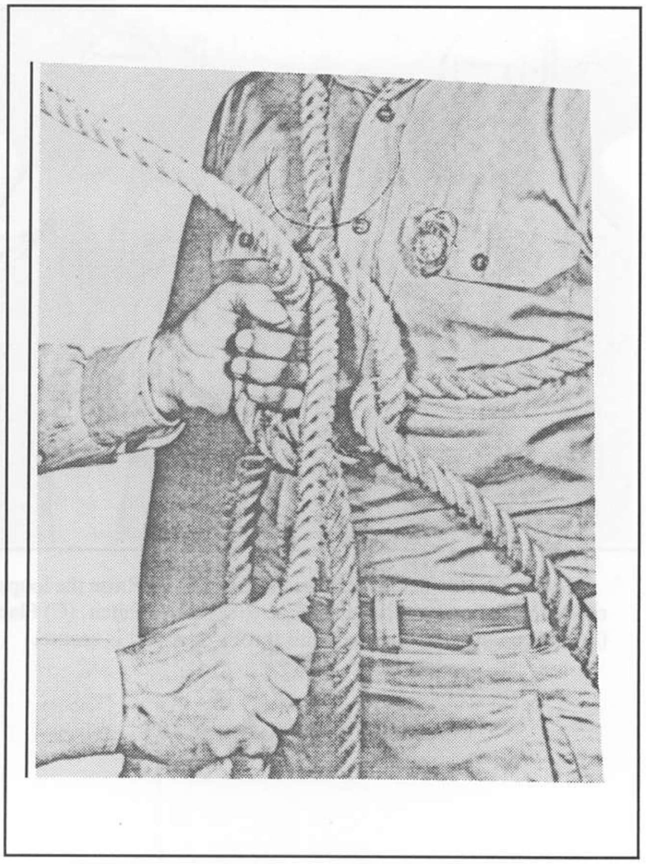


Plate 11-13. Preparing a butterfly harness; Step 4.

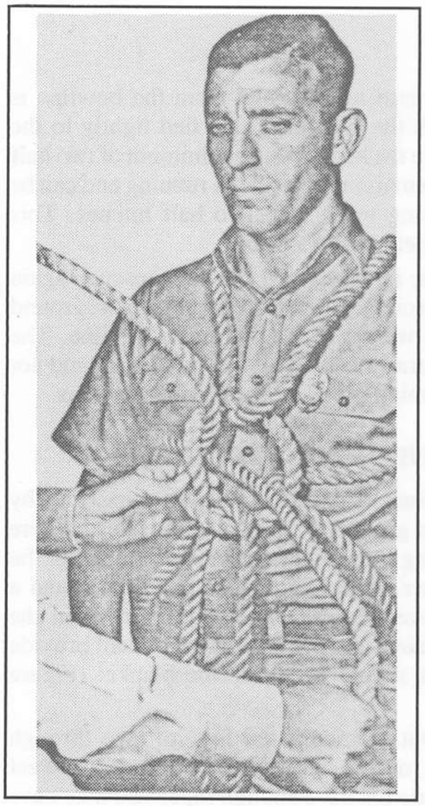


Plate 11-14.
Preparing a butterfly harness; Step 5.

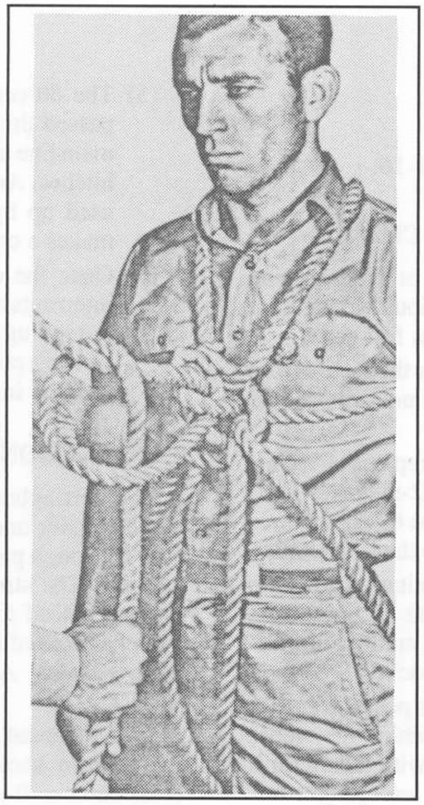


Plate 11-15.
Preparing a butterfly harness; Step 6.

Plate 11-16.
The completed butterfly harness.

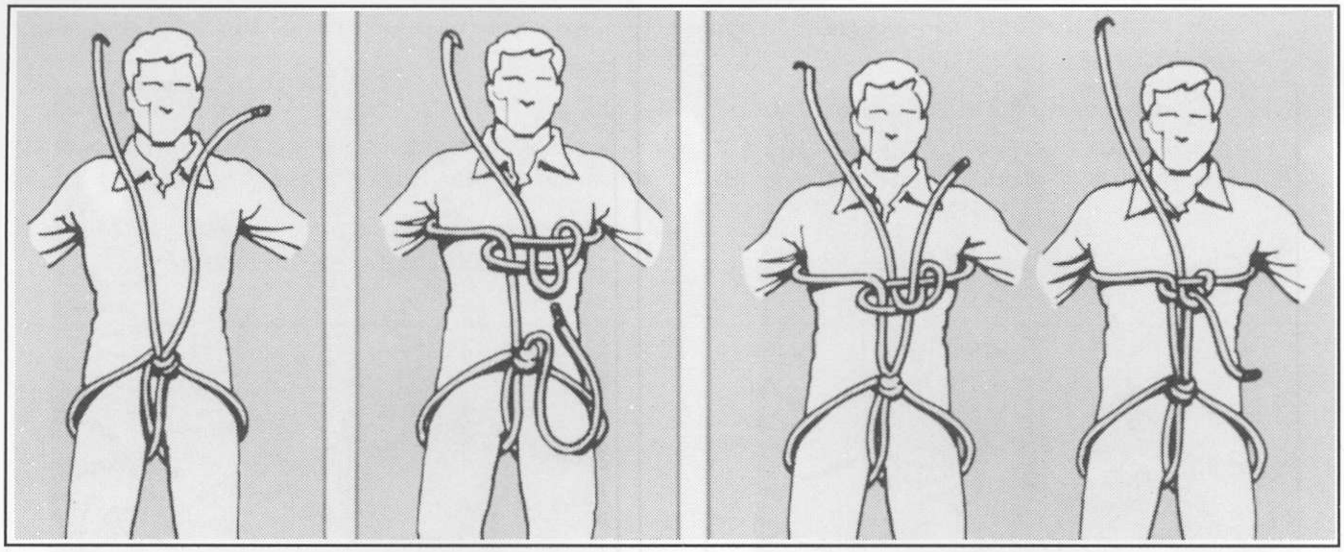


Figure 11-16. The fireman's rescue knot. (A) Raise the loops over the legs to the crotch. (B) Place a half-hitch around the chest, and make an overhand safety with a loop to secure the hitch. (C) Place the loose end of the line from the bight through the loop at the safety. (D) Pull on the working line until it rolls over and is secure.

FIREMAN'S RESCUE KNOT

(1) Make a bowline on a bight.
(2) Follow the steps illustrated in Figure 11-16.

POLE-TOP RESCUE – THE BOSUN'S CHAIR

Injury by electric shock while working on transmission lines may necessitate rescue of an unconscious victim from the top of a power pole. The procedure is as follows:

(1) One rescuer must climb the pole, clear the victim from the energized conductor and begin mouth-to-mouth resuscitation immediately.

(2) A second rescuer on the ground prepares a rescue harness by tying a bowline with a 2-metre (7-foot) loop and leaving a running end at least 60 centimetres (2 feet) long. The loop is passed up to the first rescuer.

(3) The first rescuer stops giving resuscitation for long enough to pass the loop between the victim's legs, leaving the knot just below the chin and holding the end of the loop behind the victim's back.

(4) Resuscitation is resumed as quickly as possible and, at the same time, the rescuer reaches behind the victim and lifts the loop to a position level with the victim's armpits. The two sides of the loop are brought forward, under the armpits, forming a loop on each side of the victim's body.

(5) The 60-centimetre running end from the bowline is passed through the two loops and tied tightly to the main line above the knot, using a minimum of two half hitches. Any remaining rope in the running end can be used up by tying more than two half hitches. This makes a complete bosun's chair.

(6) Once the chair is completed the first rescuer again interrupts resuscitation to tell the person on the ground to take up the weight of the victim on the line. The victim's pole strap can then be cut, but this should not be done in training practice, for obvious reasons.

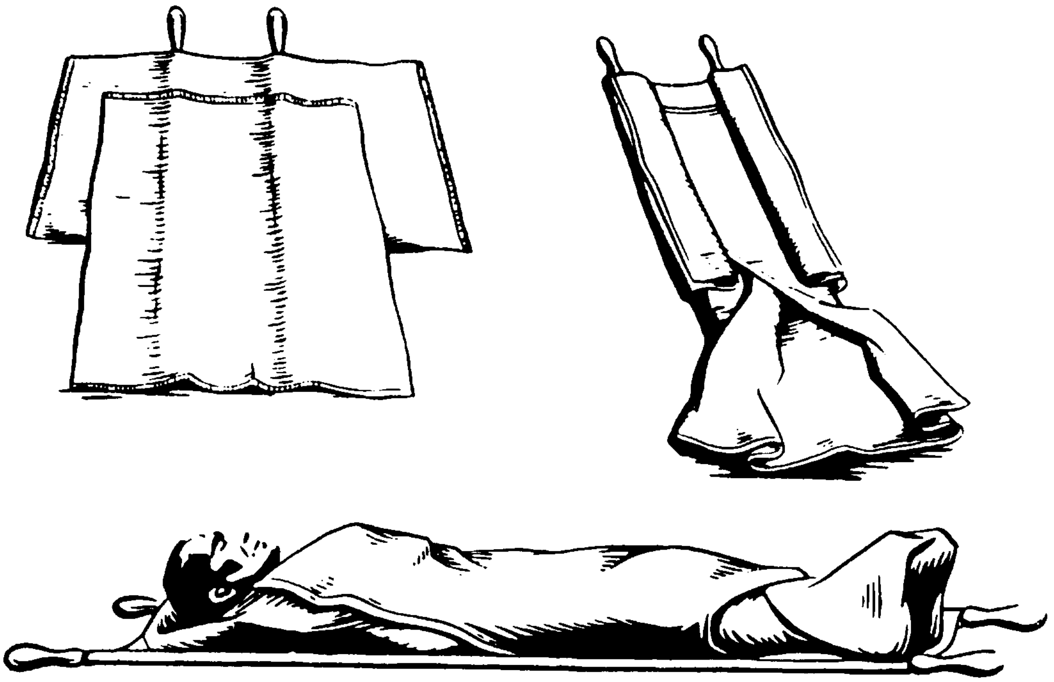
HERRINGBONE TIE-IN FOR STRETCHER

The herringbone knot is used to transport a casualty by stretcher over uneven ground or vertically. It is very secure and, if enough padding is used, it is very comfortable for the casualty. The stretcher should be padded underneath and a blanket placed to cover the casualty before putting in the stretcher. Rolled blankets on each side of the patient provide more stability. Arms should be inside the blanket (Figure 11-17).

Step 1 – Thread about 18 metres (60 feet) of rope through the bottom section of the stretcher, below the lowest crossmember. If you do not have enough rope, you may have to use an improvised lashing as illustrated in Figure 11-17, but a herringbone lashing is much preferred.

TRANSPORT OF CASUALTIES

BLANKETING A STRETCHER



SECURING TO A STRETCHER

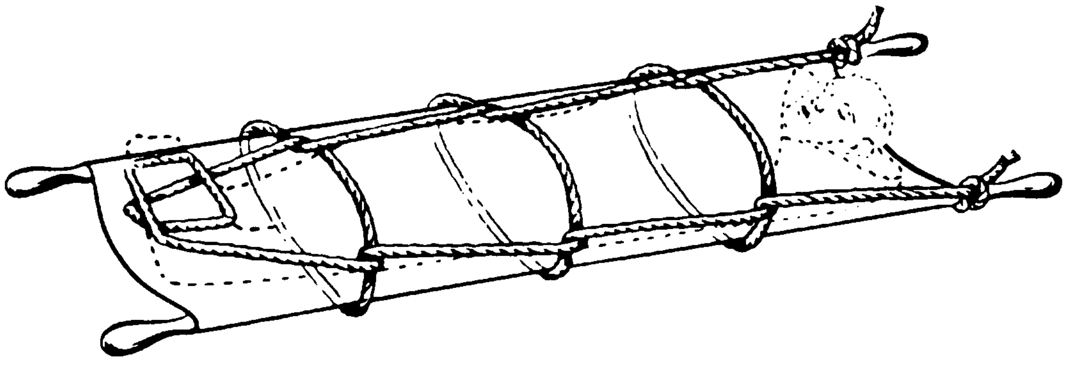


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Figure 11-17. Blanketing and securing a stretcher.

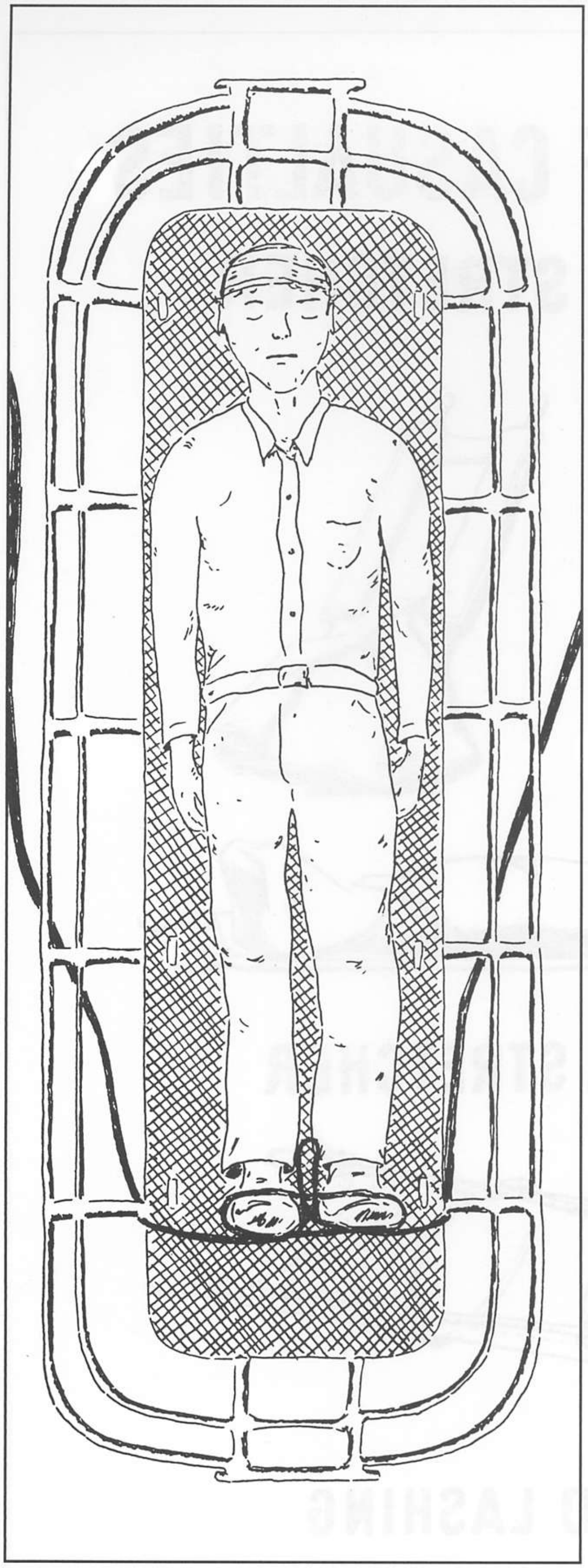


Figure 11-18. The herringbone tie-in for a stretcher; Step 2.

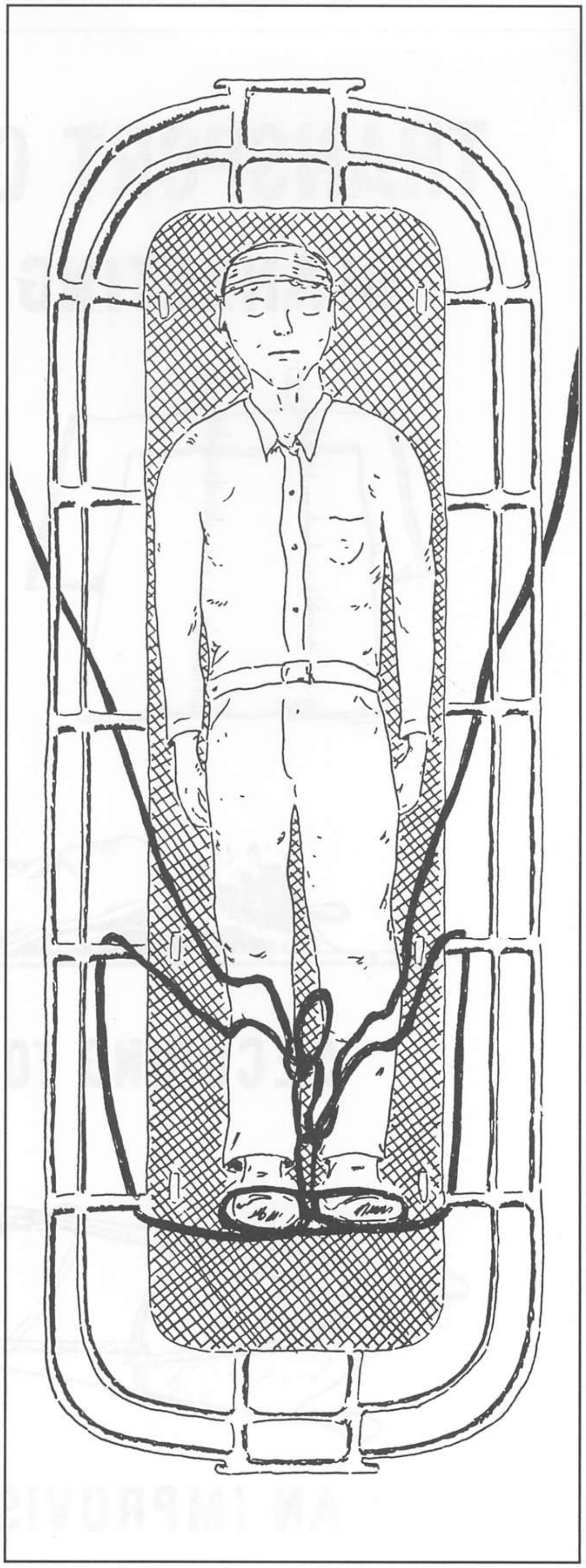


Figure 11-19. The herringbone tie-in for a stretcher; Step 3.

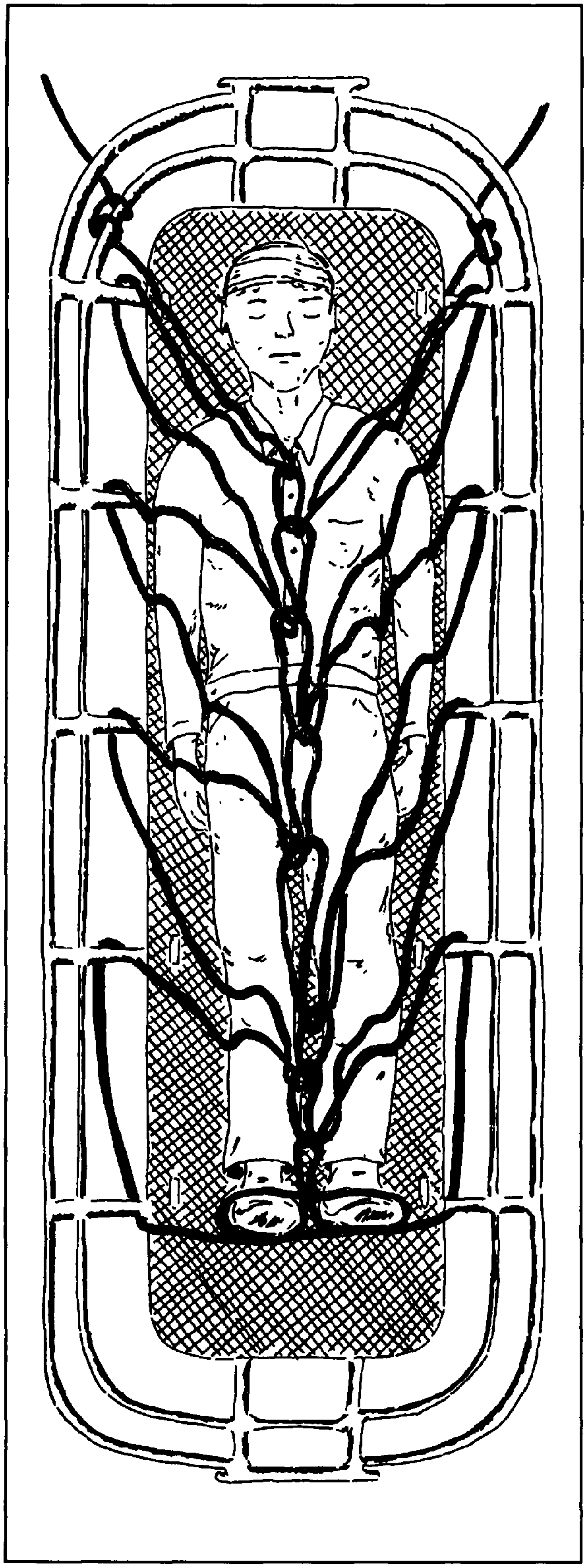


Figure 11-20. The herringbone tie-in for a stretcher; Step 5.

Step 2 – Pad below the casualty's feet to prevent slipping down when the stretcher is lifted upright. Loop the centre of the rope around the casualty's feet, or make a clove hitch. Pull the slack to make a running loop between the feet (Figure 11-18).

Step 3 – Thread one running end over the second crossmember of the stretcher on one side, and pull a bight through the loop between the feet, to make a second running loop. Repeat with the other running end, on the other side of the stretcher, pulling the bight through the second running loop to make a third (Figure 11-19).

Step 4 – Pull the loops snugly around the patient's body, but not too tight. If the casualty is conscious, ask if he is comfortable. Work up the stretcher, repeating Step 3 using each crossmember in turn.

Step 5 – When you reach the top crossmember, tighten each running end over the casualty's shoulders, making sure they are well padded, and tie off on the stretcher frame with clove hitches (Figure 11-20).

LOWERING AND RAISING SYSTEMS

Rescue teams must be able to come to the assistance of accident victims stranded in places that are difficult to reach, for example, a ledge on a bench face or steep slope with no hand-holds, or at the bottom of a stope or other inaccessible place underground. Raising and lowering systems are also required for moving equipment over obstacles and to recover victims once the rescue team reaches them.

RAPPELLING

Rappelling is a rescue technique which uses the friction between a rope and a "descender" to control a climber's rate of descent down a precipitous slope; it is commonly used in rescue work. The technique is best learned by practice, but the essential elements are as follows:

- Fasten the rappel rope securely to an anchor well back from the edge of the face you are about to descend and tie a stopper knot in the end. The safety line or belay rope should be fastened to a separate anchor. Anchors must be secure; you must be able to give first aid and prepare the victims for evacuation when you reach them, not become a casualty yourself.
- Pass a loop of rope through the large ring in a figure-of-eight descender and over the small ring (see Figure 11-21). Attach the figure-of-eight to the rappelling harness with a locking carabiner. Attach the safety rope to the harness or pass it around your chest under the armpits, and tie a bowline with a stopper knot. Pad places where the rope will pass over sharp edges while you are descending.
- Stand at the top of the descent with your back towards it. Take up the slack between the anchor and your descender (see later in this chapter). Once everyone has been checked by another team member, and communication is established with the belayer, you are ready to start the descent.
- Place your left hand on the rope well above the figure-of-eight. Your right hand will be used to control the speed of descent and should be tucked behind your right buttock. With the brake-hand closed, lean back and allow the rope to take your weight.
- Back over the edge while slowly opening your brake-hand and using it to control your speed.
- It is important to descend down the fall line, that is, keeping the rope vertical, below the anchor. Allow the rappel rope to take your full weight; avoid long jumps, they increase wear on the rope, and do not try to make use of footholds as you may slip and bring your nose in painful contact with the face of the slope. Sit back in the harness with your legs perpendicular to the slope, using them to push yourself outwards, away from any possible danger. Remember that all ropes are somewhat elastic and if the tension in the rope is constantly changing, it will not run smoothly through the descender, particularly near the end of a long descent.
- The first rappeller to complete the descent acts as safety man and can stop the descent of others by tightening the rappel rope.

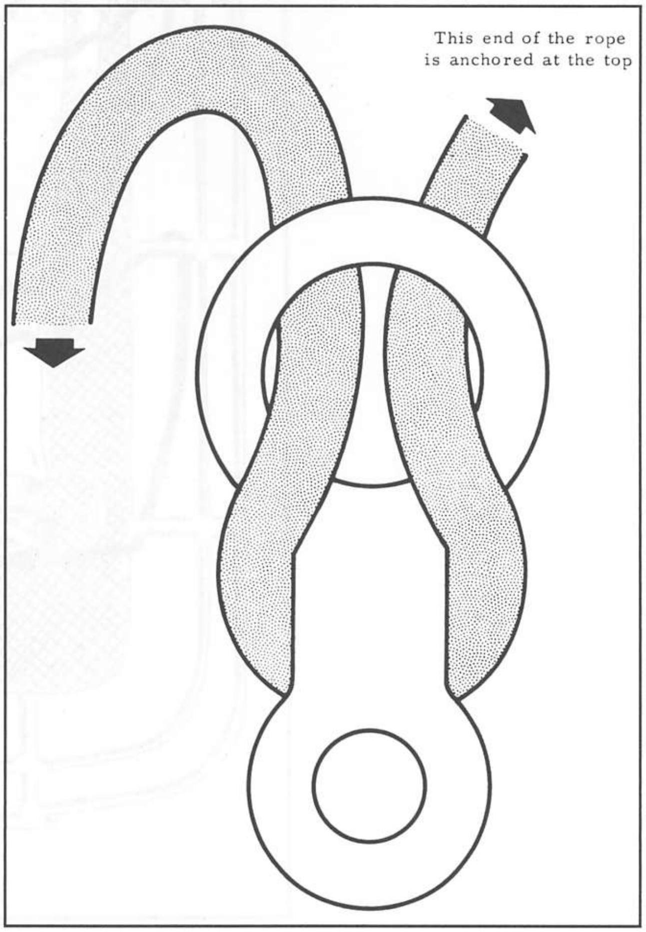


Figure 11-21. The clog figure-of-eight descender for rappelling.

Many texts recommend that rappellers keep their legs wide apart, to provide better balance, and this is sometimes necessary. However, in most cases, and particularly when following the fall line, this is not only not required but may cause difficulties. Bobbing back and forth from foot to foot will move the rappel rope from side to side and may knock down loose rock on the rappeller. Rescues are often made in areas of loose rock and this can be a serious danger. Keep your feet close together **and** keep in balance.

All descenders build up some heat from friction during the descent. It is a good habit to disconnect the descender as soon as you reach the bottom, providing you are in a safe landing spot and still on belay. The tension in the rope will tend to pull you upwards as you stand at the bottom. When you arrive, bend the knees and continue to slide down the rope, then stand up. This will release the tension and make disconnection easier.

All descenders should be tested by the magnaflux or equivalent method after every use. They should be non-destructively tested at least once a year.

PRUSSIK BELAY

When larger or slower moving loads, such as a loaded stretcher, are to be lowered, the prussik belay is the most advantageous technique. The method is simple, but some points require close attention.

For heavy loads use one or two three-wrap prussiks of 7-millimetre kermantle rope. Once the load is tied onto the belay rope with the prussik hitch, it can be clipped directly to the anchor system, or better, to a load-releasing hitch joining the prussik to the anchor. Make sure that the double fisherman bend joining the two ends of the prussik sling does not interfere with the action of the prussik hitch and is not in a position where it will press on the connecting carabiner. It is best to tie the prussik hitch so that the double fisherman bend is on the side, but closest to the carabinered end.

Unless the anchor points are quite high, the belayer will sit or kneel near the prussik and pull the rope through it as the load is raised or lowered. Avoid any slack between the prussik and the anchor system and do not pay out the rope too fast in a descent. Do not get in a position where you will be knocked over, or pinched against a rock face, if the belay is activated. The prussik itself should be just tight enough to allow the rope to be pulled through it without undue exertion. Keep one hand on the rope below the prussik. In the event of a fall, the hand on the prussik will follow the rope downwards until the tension in the anchor rope sets the prussik hitch and makes it bite the rope. There is no braking-hand in this method of belaying; it is the prussik hitch itself that bites on the rope, transferring the weight directly to the anchors.

Care must be taken to ensure that the prussik hitch does not bite unexpectedly, especially during a descent. If it does, the only way to release it is to raise the load using a pulley system or allow the prussik to move downhill by releasing the load-release hitch to slacken the tension.

PULLEY SYSTEMS

When the accident victims are located below the point where they can be brought to safety, there is seldom any alternative but to raise them by using rope systems, as it is the exception, rather than the rule, for accident sites to be easily accessible by other lifting equipment, such as cranes. Though gravity and friction are allies during lowering operations, they are enemies when attempting to raise a patient. Systems that provide mechanical advantages must be used to carry out such an operation safely. For basic rescue, pulley systems are the answer to providing the needed mechanical advantage. Occasionally modified rope winches are used with success, however, their extra weight and the possibility they may be damaged or left behind means that any group using them should also have a sound knowledge of pulley systems.

Simple and compound pulley systems are easily distinguished. The simple system has one end of its rope fastened to either the anchor or the load (the object to be moved) and the other is run alternately through pulleys on the load and anchor with the loose end attached to whatever provides the lifting power. The compound system is simply a second simple pulley system pulling on the loose end of the first (ganged).

Simple pulley systems are illustrated in Plates 11-17 to 11-21.

Simple systems, such as those illustrated, can be expanded to produce a mechanical advantage (MA) up to 5:1, but remember:

- You never get something for nothing; there must be a trade-off. If the pulley system allows you to move the load using less force, you must apply this force through a greater distance; the MA tells how much. If the MA is 5:1 you will use one-fifth the force, but have to pull in five times as much rope.
- When the rope is tied to the load the MA will be an odd number. When the rope is tied to the anchor it will be an even number.
- The MA for all pulley systems is also calculated as the number of metres of rope pulled in to move the load 1 metre. A quicker way to determine the MA for a simple pulley system is to count the number of ropes between the load and the anchor. In this case the pullers are considered part of the anchor since their feet are on the same ground the anchor is secured to. Hence, if the rope is extended between the pullers and load, it is counted, but if extended between the pullers and a pulley on the anchor, it is not.
- Care must be taken to see that the pulleys are lined up properly and that the ropes do not twist and rub on each other, reducing efficiency. Sometimes a stick stuck through a carabiner and touching the ground can control difficult twisting problems. Due to this problem, simple pulley systems with mechanical advantages greater than 5:1 are very seldom warranted unless some of the pulleys can be separated on different anchors to prevent rubbing.

Most basic rescue situations can be handled with pulley systems with mechanical advantages of 2:1, 3:1 or 4:1. In cases where this is not sufficient, compound pulley systems of 6:1, 8:1, 9:1 or more can easily be arranged. A compound pulley system is two simple pulley systems ganged piggyback, that is, one pulley system pulling on the other. Though

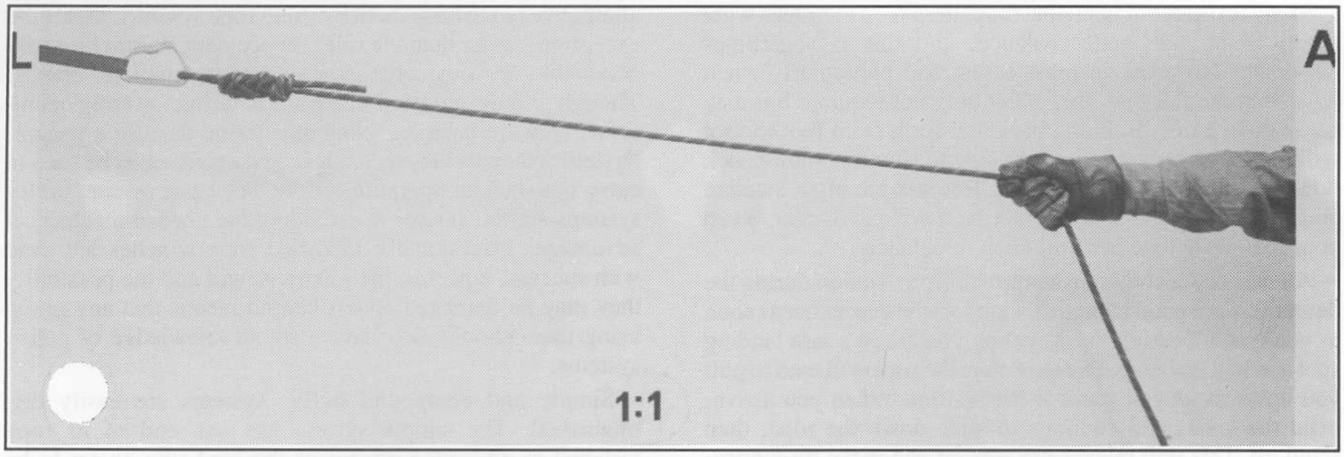


Plate 11-17. A basic "raising system" using no pulleys. The rope is tied to the load; pull directly on the rope. Pull in 1 metre of rope to move the load 1 metre (MA = 1:1).

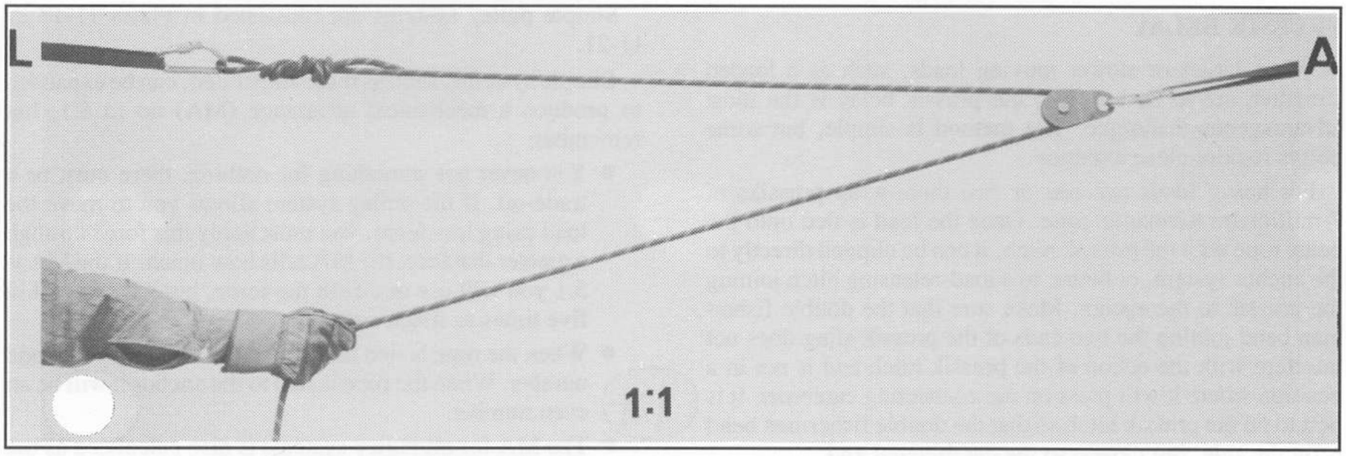


Plate 11-18. A single-pulley system with no mechanical advantage. The rope is tied to the load, threaded through a pulley on the anchor and pulled in the opposite direction. This simple pulley on the anchor does nothing but change the direction of pull. This may help if it allows you to pull downhill rather than up, but it does not increase the mechanical advantage.

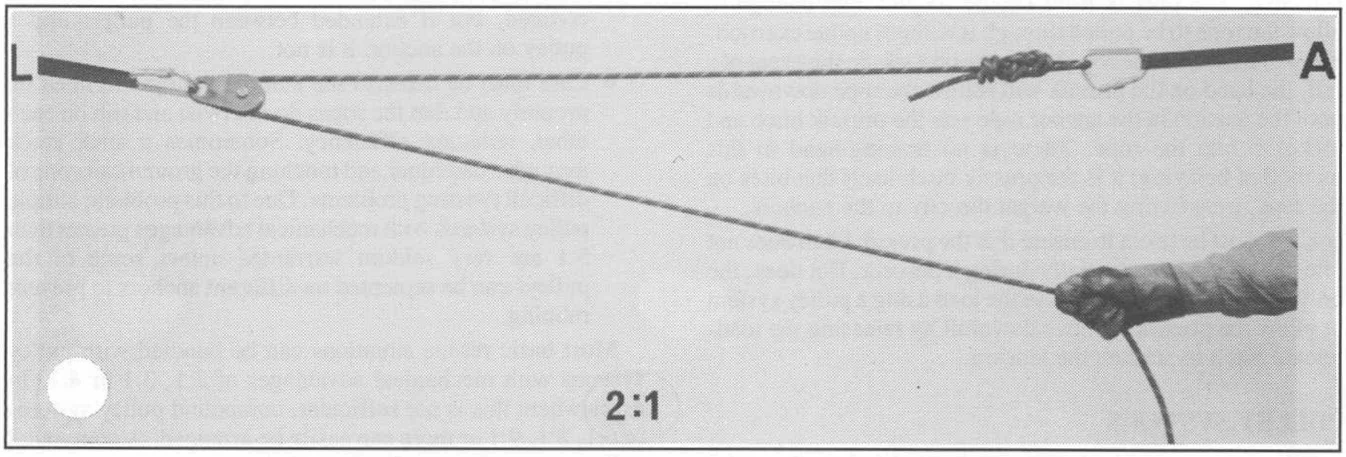


Plate 11-19. A single-pulley system with a mechanical advantage of 2:1. The rope is tied to an anchor, threaded through a pulley on the load and pulled upwards toward the anchor. Pull in 2 metres of rope to move the load 1 metre (MA = 2:1).

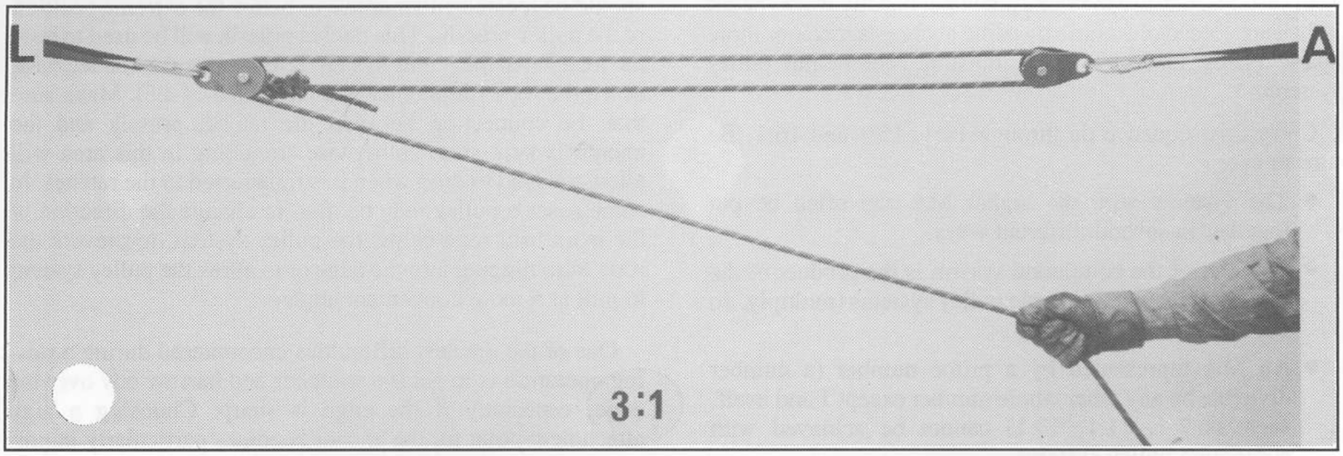


Plate 11-20. A simple two-pulley system with a mechanical advantage of 3:1. The rope is tied to the load, threaded through a pulley on the anchor and a pulley on the load, and pulled towards the anchor. Pull in 3 metres of rope to move the load 1 metre (MA 3:1).

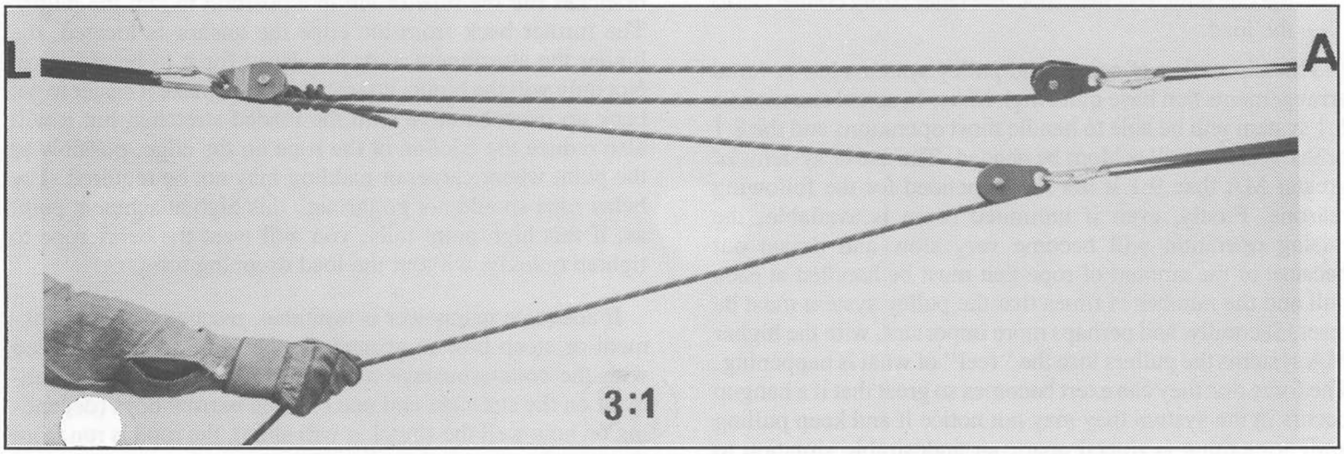


Plate 11-21. A simple three-pulley system with a mechanical advantage of 3:1. The rope is tied to the load, threaded through a pulley on the anchor, back to a pulley on the load, and back again to a second pulley on the anchor, and pulled away from the anchor. This does not increase the mechanical advantage over the system in Plate 11-20, but reverses the direction of pull. This is always the case when the last pulley in the system is on the anchor.

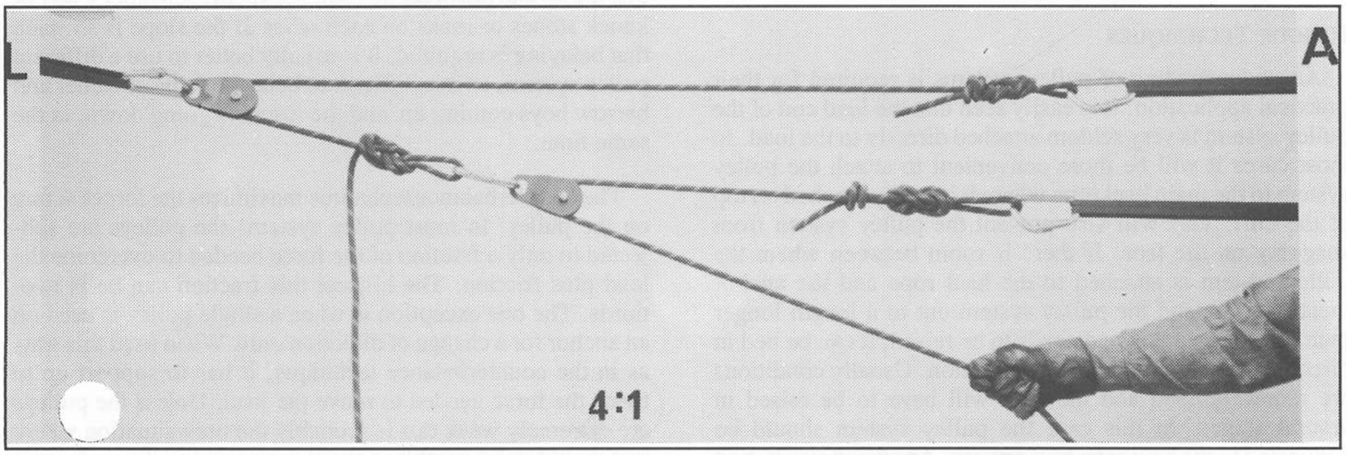


Plate 11-22. A multiple-pulley system with a mechanical advantage of 4:1. A 2:1 system is pulling on a 2:1 system. Pull in 4 metres of rope to move the load 1 metre (MA = 4:1).

both systems may use the same anchor, it usually works better if they are spread out a little by using anchors a metre or more apart. Plates 11-22 to 11-25 illustrate compound pulley systems.

Carry this sequence on through 12:1, 15:1 and 16:1. Be sure to note:

- The systems with the higher MA can often be put together in several different ways.
- The MA of the compound system is the product of the MAs of the separate simple pulley systems (multiply, do not add).
- An MA represented by a prime number (a number divisible by any other whole number except 1 and itself, such as 7:1, 11:1, 13:1) cannot be achieved with compound pulley systems.
- When the two components of the compound system have unequal MAs (such as 2:1 and 3:1), the load can be moved the furthest distance before the system must be reset by having the system with the higher MA pull on the one with the lower MA, the latter being connected to the load.

This discussion of compound pulley systems has covered arrangements that have quite high MAs. In actual situations a 6:1 system will be able to handle most operations and the 8:1 or 9:1 systems will seldom be needed. The use of systems of greater MA than 9:1 is not recommended for the following reasons. Firstly, even if unlimited room is available, the raising operation will become very slow and drawn out because of the amount of rope that must be handled at each pull and the number of times that the pulley system must be reset. Secondly, and perhaps more important, with the higher MA systems the pullers lose the "feel" of what is happening. The force that they can exert becomes so great that if a hangup occurs in the system they may not notice it and keep pulling until something is ripped apart; an undesirable situation to say the least. Since the average rescuer can pull with a maximum force of 25 kilograms (55 pounds), a rough calculation should be made, taking into account the MA and number of pullers, to see that the system will not be overstressed, particularly the prussik which is liable to slip at around 500 kilograms (1100 pounds).

RESCUE TECHNIQUES

An understanding of pulley systems is required for their practical application. It is easily seen that the load end of the pulley system is very seldom attached directly to the load. In most cases it will be more convenient to attach the pulley system to the main haul rope where it is easily reached on top of the cliff. This will also prevent the pulley system from snagging on the face. If there is room between where the pulley system is attached to the haul rope and the anchor location to extend the pulley system out to a length longer than the distance the load needs to be raised, it can be tied in directly and used for a one-lift operation. Usually conditions are more cramped and the load will have to be raised in several stages. In this case the pulley system should be connected to the haul rope by a prussik. Another prussik, tied around the haul rope and connected to the anchor system, should be located either above or below the extreme position of the pulley prussik. This ratchet prussik will be used to hold the load when the pulley system is relaxed and extended back down the rope for another bite (*see* Plate 11-26). Make sure that the connection between the ratchet prussik and the anchor is kept short, otherwise stretching in this area will allow the load to drop when it is transferred to the ratchet. In some cases a pulley may be used to change the direction of the main haul rope below the pulley system, to prevent the rope from digging into the edge or to allow the pulley system to pull at a more convenient angle.

One of the greatest difficulties encountered during a raising operation is to get the stretcher and barrow boy over the edge, especially if the edge is sharp. Choosing a high attachment point for the anchor becomes particularly important, more so than in a lowering operation. Because raising operations are more likely at lower elevations, there are likely to be standing trees that can be used as the high attachment. When able to place a sling high in a tree to direct the main rope, be sure to use a pulley at this point and see that no branches rub the rope or are in a position to jam the pulley. The further back from the edge the anchor is located, the higher the attachment must be placed for it to be effective. Not only will the higher attachment point make it easier to get back up over the edge with the loaded stretcher, but it will also reduce the friction of the rope on the edge, possibly to the point where carpet or padding may not be required. The belay rope should not go through this high attachment point as, if this high point fails, you will want the belay rope to tighten quickly, without the load dropping too far.

If adequate manpower is available, rescue on an embankment or steep broken ground can be very quickly handled with the counterbalance technique. Using the head attachment on the stretcher and one or three barrow boys (depending on how well the stretcher will slide), the rope is run from the stretcher up to a single pulley secured to an anchor. A number of loops are tied in the rope, or slings attached to the other side of the pulley, so that several rescuers can easily walk down the hill exerting enough force to slightly over counterbalance the stretcher and barrow boys on the way up. This technique should only be used when the embankment is open enough, or there are separate trails through the bush, so that the up and down parties will not get in each other's way or knock stones or rocks on each other. If the slope is so steep that belaying is required, it is usually better to use a different pulley system, as it is difficult to belay both the stretcher and barrow boys coming up, and the rescuers going down, at the same time.

The counterbalance technique maximizes the forces acting on the pulley. In most pulley systems the pulleys are subjected to only a fraction of the force needed to overcome the load plus friction. The highest this fraction can be is two-thirds. The one exception is when a single pulley is used on an anchor for a change of direction only. When used this way, as in the counterbalance technique, it has to support up to twice the force needed to move the load. Unless the pulleys are extremely weak this is probably the only situation where you would use a carabiner chain connected to the main rope and the anchor, as a backup to the pulley.

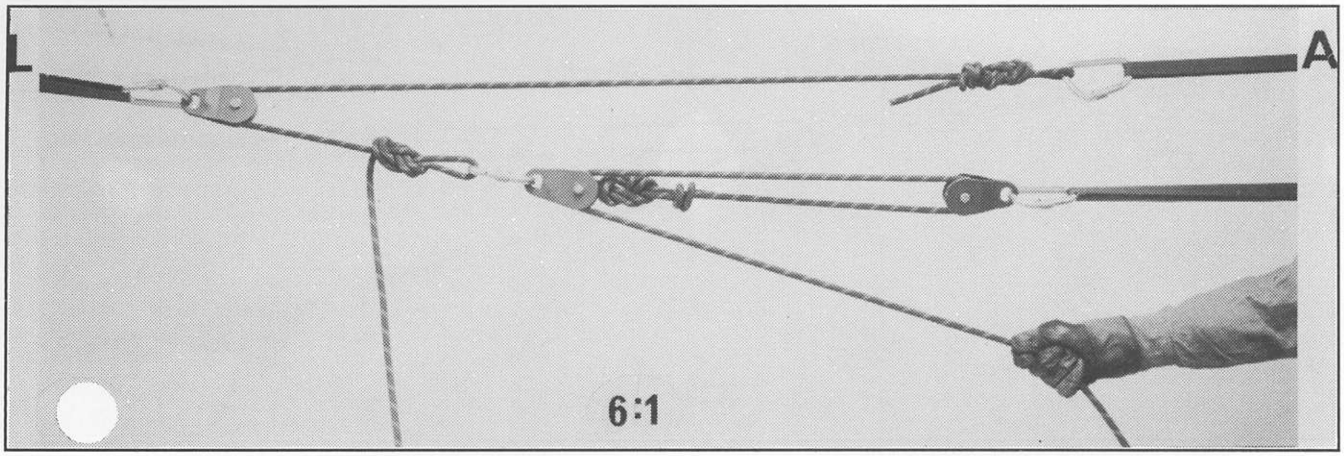


Plate 11-23. A multiple-pulley system with a mechanical advantage of 6:1. A 2:1 system is pulling on a 3:1 system. Pull in 6 metres of rope to move the load 1 metre (MA = 6:1).

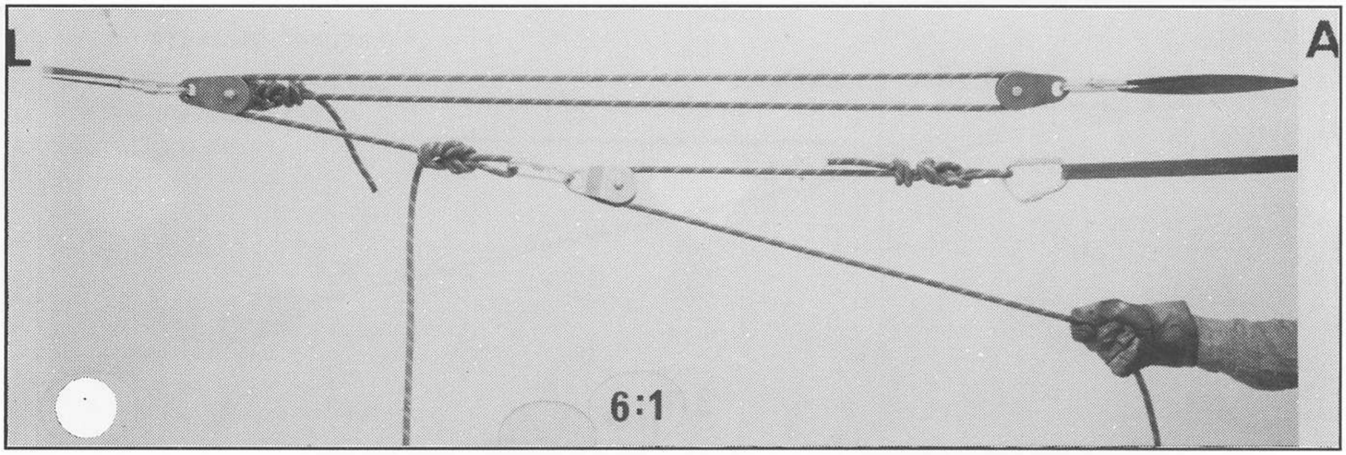


Plate 11-24. A multiple-pulley system with a mechanical advantage of 6:1. A 3:1 system is pulling on a 2:1 system. The result is the same as in Plate 11-23.

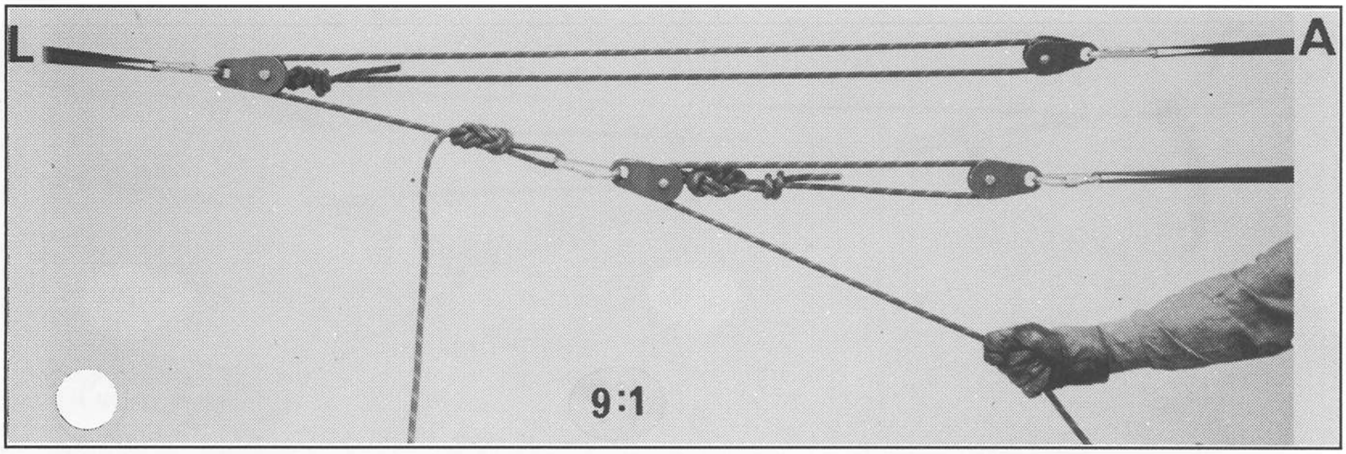


Plate 11-25. A multiple-pulley system with a mechanical advantage of 9:1. A 3:1 system is pulled by a second 3:1 system. Pull in 9 metres of rope to move the load 1 metre (MA = 9:1).

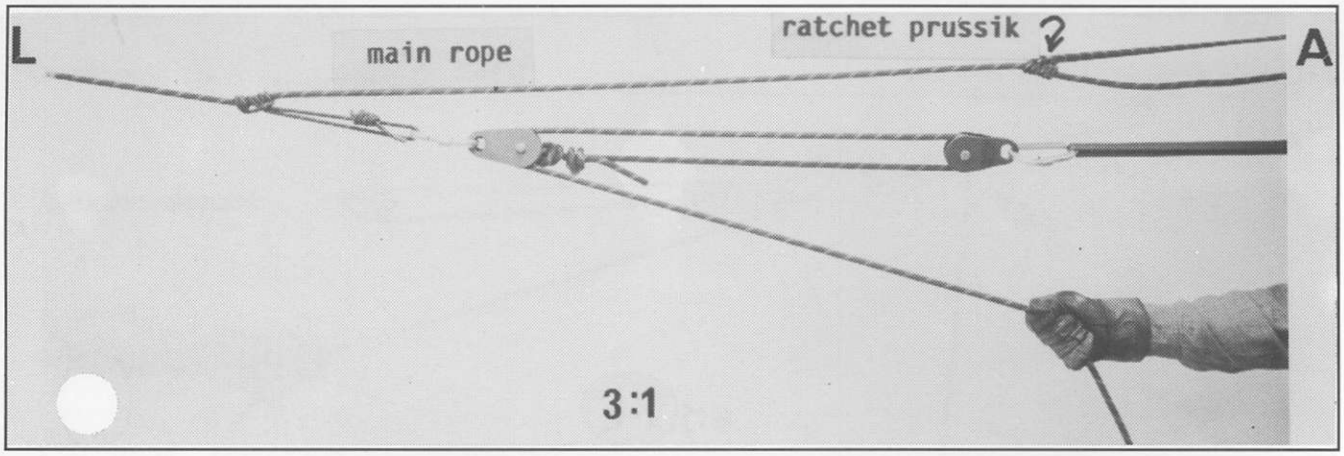


Plate 11-26. A multiple-pulley system with a ratchet prussik.

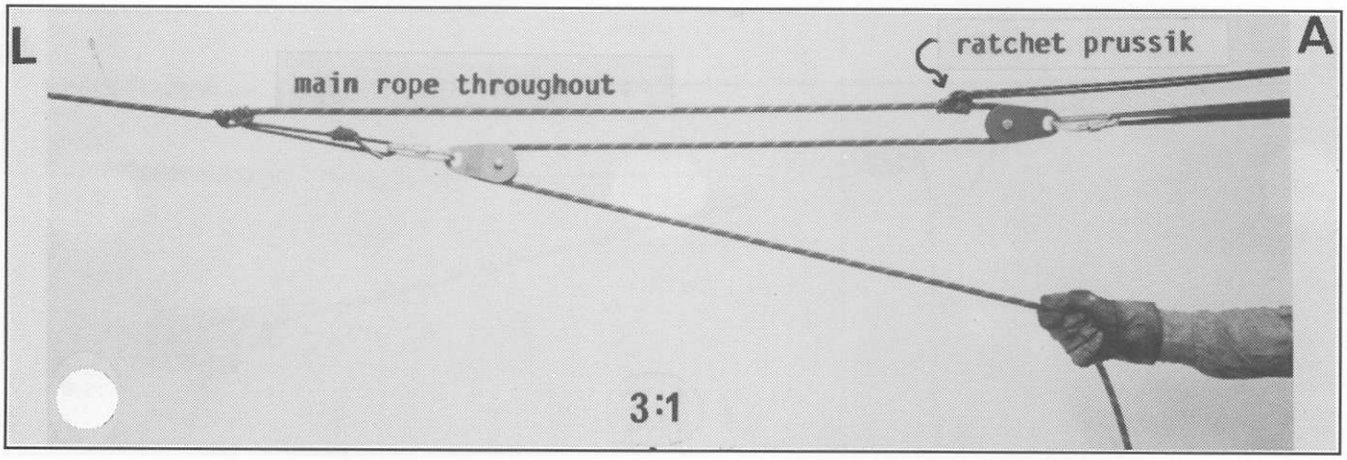


Plate 11-27. A simple two-pulley system with a ratchet prussik and using the minimum of rope.

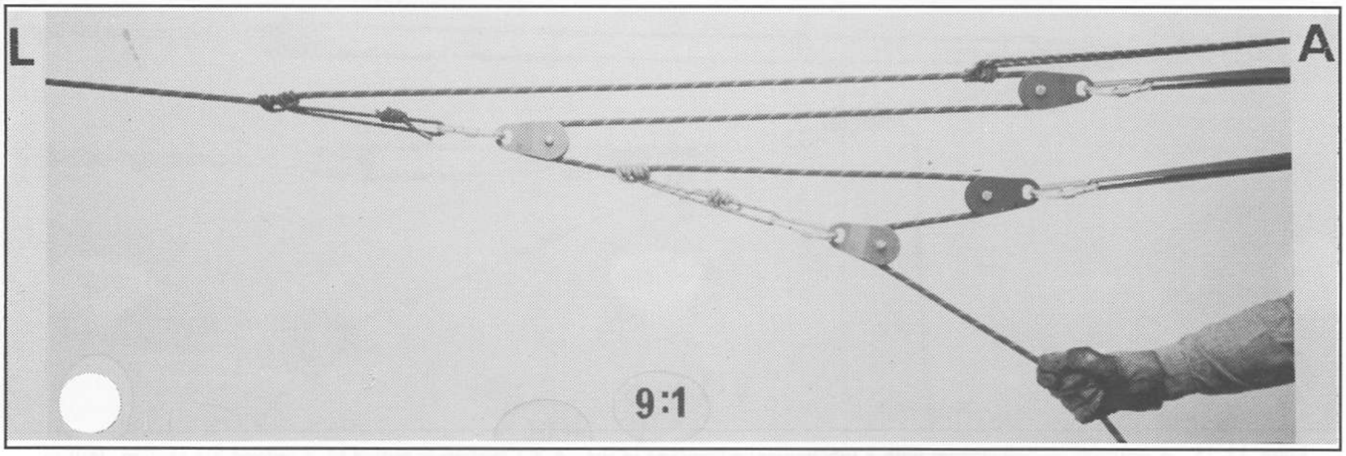


Plate 11-28. A multiple-pulley system using the minimum of rope.

In all of the above examples separate ropes have been used for the pulley systems and connected to the main haul with a prussik. Often this is the easiest way to keep things straight, particularly when different coloured ropes are used for each part of a compound system. When only a short length of rope is available it is sometimes necessary to use the main haul rope itself as part of the pulley system. This presents no difficulties if the first simple pulley system has an uneven-numbered mechanical advantage.

To set up a pulley system in this way, start with a rope tied directly to the load. Bring the rope through a pulley on the anchor and back to a pulley attached part way down the rope by a prussik (*see* Plate 11-27). If you now pull toward the anchor you will see that you have a 3:1 system, this time using only the main haul rope. Another advantage to this way of rigging the system, besides not requiring an extra rope, is that a prussik around the main haul rope, near where it enters the first pulley, can easily be set to become a self-minding ratchet. The pulley should have flanges that will prevent the prussik from being drawn into the pulley, and the connection between the prussik and the anchor should be kept as short as possible to prevent too much dropping of the load when the pulley system is relaxed.

If this single system is not sufficient to do the job, two more pulleys can be added, making a 5:1 system; the system can be compounded by pulling on it with another pulley system. If no extra rope is available, the same haul rope can be used again (as previously) resulting in a 9:1 MA using only one rope and four pulleys. This is a useful system when a high MA is required and equipment is in short supply (*see* Plate 11-28).

The strength needed to reset compound systems is often not appreciated. Help the man resetting it by having someone else pull the second pulley system out while he pulls out the first system and resets the prussik. He will appreciate it.

ANCHOR POINTS AND SYSTEMS

Before any of the techniques described in the previous section can be used to rescue a person who is injured or stranded, the ropes or lowering and raising systems must be secured to a substantial anchor. Anyone moving on the face of the slope must be secured by means of two separate ropes. The belay rope, acting as a backup to the main rope, is usually only snug while the main rope carries the full weight of the load. The main rope may be stationary, as in rappelling, or it may be moving, as during a lowering or raising operation.

In basic slope rescue, use will be made of trees, rock outcrops or boulders, buried objects ("deadmen") and stakes (pickets) as **anchor points**. In most cases two or more anchor points will be connected together with rope or webbing to form an **anchor system**. This allows the security of several anchor points to be brought together to a common point where the main attachment is made. Because the belay rope must be secured independently of the main rope, there will be a minimum of two **separate** anchor systems at the top of the slope. Occasionally additional anchor points or systems may be established to prevent equipment from being lost or for a belay or tie-in for crew members working near the edge.

NATURAL ANCHOR POINTS

The most common objects used as anchor points in basic slope rescue are trees, rock outcrops and boulders. They come in all shapes and sizes and offer varying degrees of security from "bombproof" to "questionable". There are no firm rules relating size or appearance to the level of security provided. Judgment regarding the safety of natural anchor points will be developed through experience. A worthwhile maxim is: "If you are the least bit unsure, backup your anchor point with another". Indeed, it is good practice to always use at least two anchor points for each anchor system even when it serves as a backup to one considered "bombproof". In a real operation, when speed is critical, there is a temptation to do without a backup anchor point, in order to save time. Avoid it! You should not entrust your well-being, or the safety of the patient, to a single anchor point. Remember that the main rope and the belay rope must be secured to separate anchor systems at the top of the slope. Even in "worst case" situations, each system should have one "bombproof" anchor point.

Trees provide good anchors for surface rescue operations in most parts of British Columbia. Clearly a tree a metre in diameter with a full green crown 30 metres or more above the ground can be considered a substantial anchor. When considering small trees, consider their size and condition, but also pay particular attention to the root system. Roots growing in a mat composed of moss and small plants with very little soil may give way easily, even on a large tree. Ropes can be tied directly to trees, although many rescue crews favour the use of a sling around the tree to avoid damage to the rope from pitch oozing from the bark. In any case, make the attachment as close to the ground as possible, to prevent leverage on the tree.

Rock outcrops must also be examined critically before using them as anchors. Is the rock sound and firmly attached? Special care should be taken to pad or remove any sharp edges that may cut the sling and to ensure that the face of the outcrop opposite the pull does not slope up in such a way that the sling will slide off.

Before using a large boulder as an anchor, give careful consideration to its weight, especially if it is sitting on the surface of the ground. Usually boulders are partially buried or wedged in among other boulders, adding to their stability. If you are thinking of using an isolated boulder, be sure it is massive enough to resist any of the forces your systems could possibly apply.

A number of points should be kept in mind when using slings to attach pulley systems to trees, outcrops or boulders:

- Do not overstress the sling by tightening it around the object used as an anchor. Allow it to hang loose so that it forms a sharp "V" when it takes up the weight of the load. When the angle between the two sides of the sling, at the point the load is attached, is small, the stress in the sling is roughly half the weight of the load. If the sling is tightened, the angle at the attachment point increases and so does the stress in the sling material. At an angle of 120° the stress on each side of the sling equals the load applied and if the sling is tightened further, the stress in the sling will be greater than the load it is holding. In practice, keep the angle between the two sides of the sling less than 90° (*see* Plate 11-6).

- When using a carabiner to connect the rope to the two ends of a sling that has been double-looped around a rock or tree, remember that carabiners are designed for end-to-end loading. Even though the the angle between the sides of the sling is less than 90°, the carabiner is subject to three-way loading and may be pulled open. Avoid this situation!
- Any tendency for the sling to slip up or down the tree trunk can be prevented by taking an extra turn around the tree before the two ends of the sling are joined (*see* Plate 11-6). When the load is applied the extra wrap will cinch up on the tree and prevent the sling from moving. An alternative is to pull one bight of the doubled sling through the other, again forming a constriction on the tree. However, if the bight comes off the side of the tree (for better cinching effect), both bights will bend back sharply on themselves and the pulley effect will double the strain at this weak point. It is better to leave the bights in front of the tree, toward the direction of pull; this will still give a moderate cinching effect.

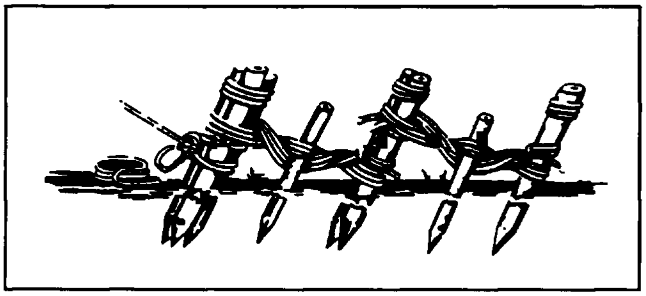


Figure 11-23. A picket holdfast.

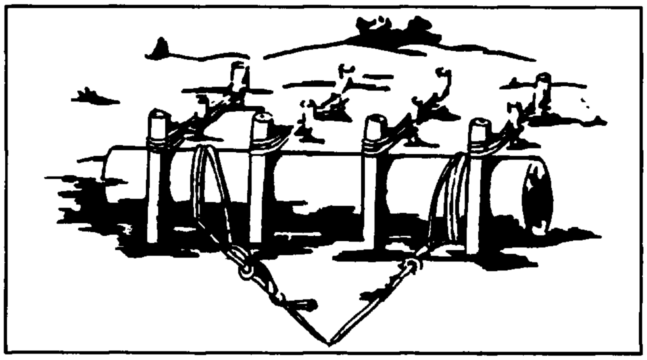


Figure 11-24. A holdfast using a combination of a log and pickets, and suitable where the ground is too hard to bury a deadman.

BUILDING ANCHOR POINTS

THE "DEADMAN"

In areas where there are no trees and the rock is of such poor quality that it cannot be used, alternative forms of anchoring must be found. In most cases a "deadman" is used. A deadman is simply an object with an attached sling, buried so that the end of the sling remains on the surface where easy connections can be made (Figure 11-22). It has been used successfully in compact soil, sand, broken rock, talus, boulder fields and even snow. A log makes a good deadman but it must be sound with a minimum diameter of 20 centimetres (8 inches) and a minimum length of 2 metres (7 feet). If you expect that a log will not be available near the rescue site, carry a substitute with you.

The procedure is to dig a trench, 60 to 150 centimetres (2 to 5 feet) deep, perpendicular to the expected direction of pull. After looping a long sling around the centre of the log, dig a smaller slit from the centre of the trench toward the direction of pull, so when the log is dropped into the trench, the sling will lie in the slit and not pull directly up on the log. As you fill in the trench to bury the log, be careful not to damage the sling. If you keep excessive weight off the sling you will be able to retrieve it after the operation without digging up the log.

You should carry a shovel for working in soil or sand, however, loose rock and talus are often better moved one piece at a time, by hand. On loose rock slopes pile additional material on top and in front of the deadman. On boulder fields, a long boulder may be used as the deadman and covered with other boulders.

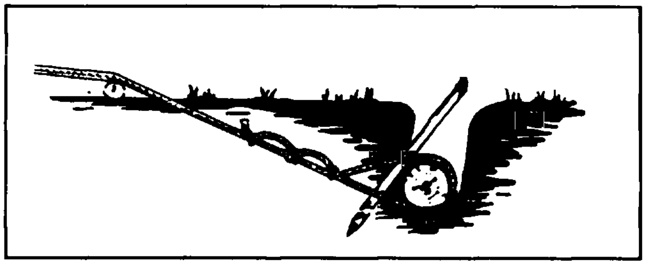


Figure 11-22. A "deadman" anchor point.

PICKET "HOLDFASTS"

Pickets are stakes of wood or metal, 75 to 150 centimetres long, that are driven into the ground with the top leaning slightly backward from the direction of pull (Figure 11-23). They are almost always used in groups, either in a fan pattern (connected by an equalizing sling) or in series (with each one tying back the one in front). In difficult ground, where the digging is hard, they can be used in combination with a log, as illustrated in Figure 11-24. Pickets are usually faster and more convenient to use than a deadman, however, in coarse or rocky soil they cannot be driven properly. In areas where there is little vegetation, the prudent rescuer will always take along a sledge hammer and several metal fence posts to use as pickets; this will avoid a situation where he finds himself tied off to a sagebrush.

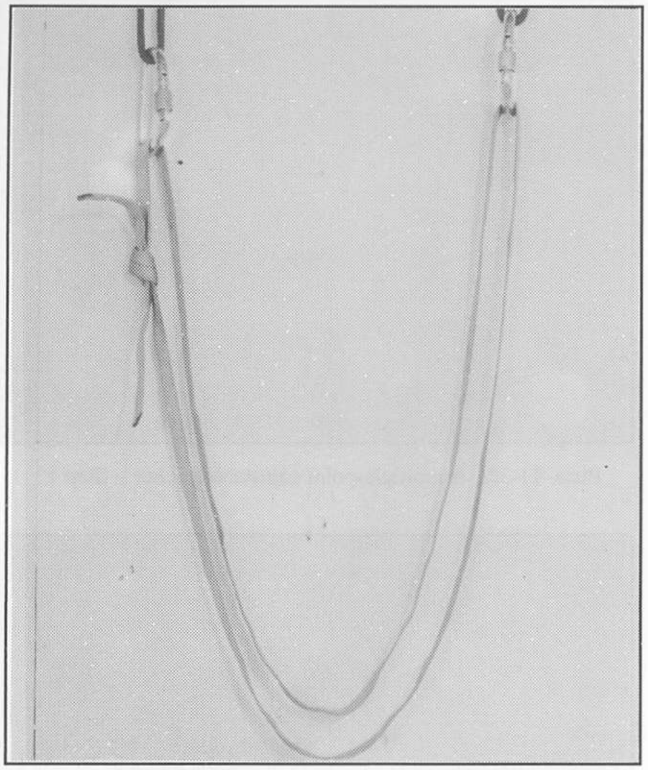


Plate 11-29. A two-point anchor system complete with web sling – Step 1.

ANCHOR SYSTEMS

Several anchor points can be linked together with a sling or rope to form an anchor system. Some anchor systems equalize the load distribution between the anchor points; others do not. The choice of system will depend on how you rate the security of the individual anchor points, and whether the direction of pull will remain constant or move from side to side.

TWO-POINT ADJUSTABLE ANCHOR SYSTEMS

If you have two secure anchor points it is easy to connect them with a doubled rope or webbing sling so that the attachment point is at the apex of a "V" pointing towards the load (Plate 11-30). As already discussed under "Anchor Points", the angle of the "V" should be less than 90°. However, if the direction of pull changes during the course of the operation, or turns out to be slightly different from that anticipated, one anchor point in the system will bear more than its share of the load and, should it fail, the entire system will be lost. Instead of clipping the carabiner holding the load to the doubled sling, make a figure-of-eight in the sling (Plate 11-31) and give a half twist to one loop before clipping on the carabiner (Plates 11-32 and 11-33). This forms a two-point adjustable anchor system. If either anchor fails the main carabiner and attachments will move forward a little, but the sling will tighten up around the carabiner and stop the fall.

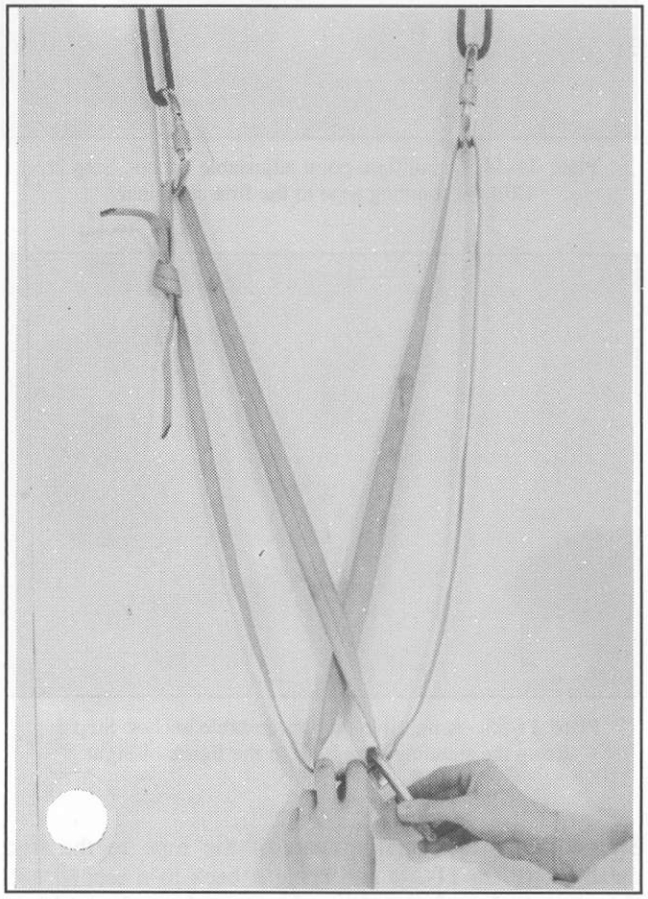


Plate 11-30. A two-point anchor, give a half twist – Step. 2.

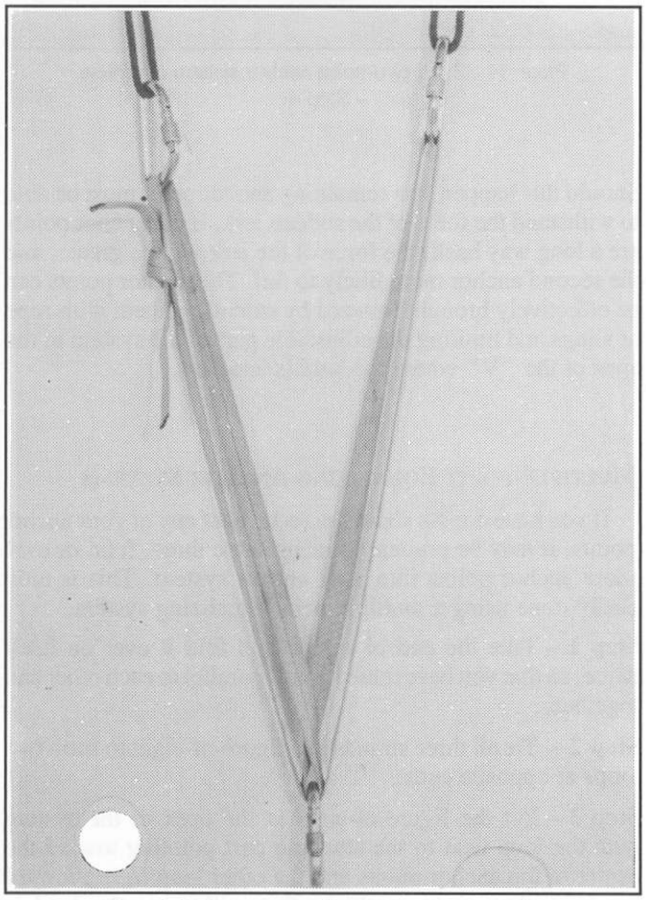


Plate 11-31. A two-point anchor system with carabiner – Step 3.

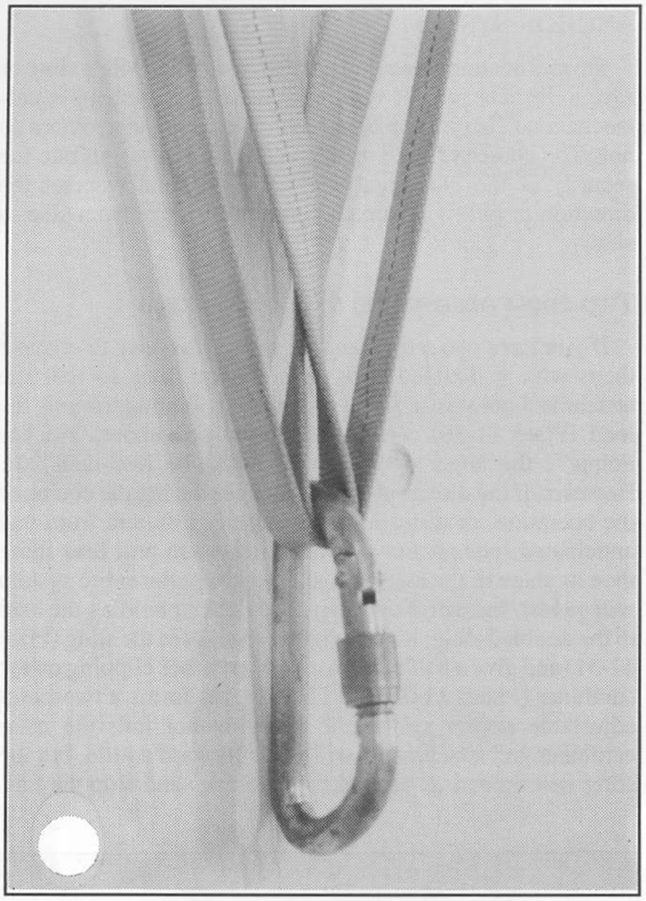


Plate 11-32. A two-point anchor system complete – Step 4.

Should this happen, the remaining anchor point must be able to withstand the force of the sudden jerk. If the anchor points are a long way back, the force of the jerk will be greater and the second anchor more likely to fail. The anchor points can be effectively brought forward by extending them with rope or slings and limiting the adjustable part of the system to the apex of the "V" where the load is attached.

MULTIPLE-POINT EQUALIZING ANCHOR SYSTEMS

If you have doubts about the security of any of your anchor points, it may be prudent to incorporate three, four, or even more anchor points into your anchor system. This is most easily done using a multiple-point equalizing system.

Step 1 – Take the end of a rope and fold it over on itself twice, so that you have three strands parallel to each other and together.

Step 2 – Tie all three strands in a figure-of-eight to form two loops at opposite ends.

Step 3 – Put the figure-of-eight at the apex of the system with the loop next to the standing part pointing toward the centre of the anchor points and the other loop facing toward the load. The main carabiner that will carry the load is clipped into this loop.

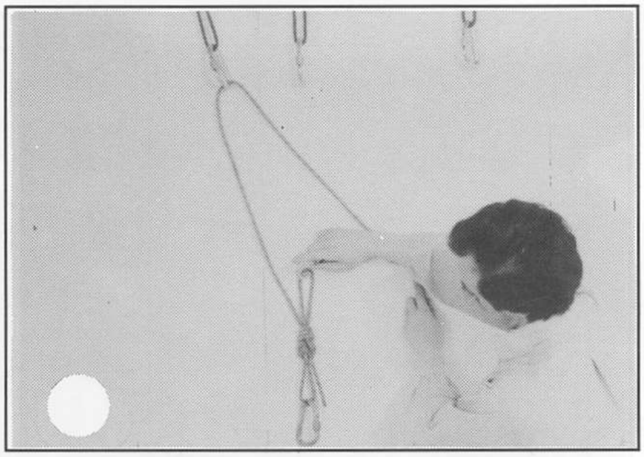


Plate 11-33. A multiple-point adjustable anchor – Step 1.

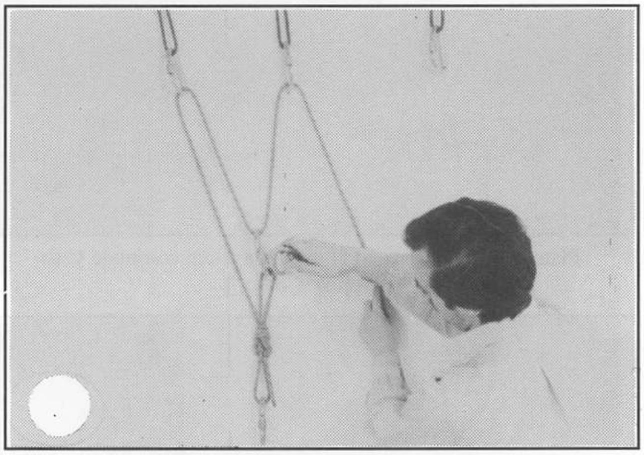


Plate 11-34. A multiple-point adjustable anchor. Step 2: Clip the standing rope to the first carabiner.

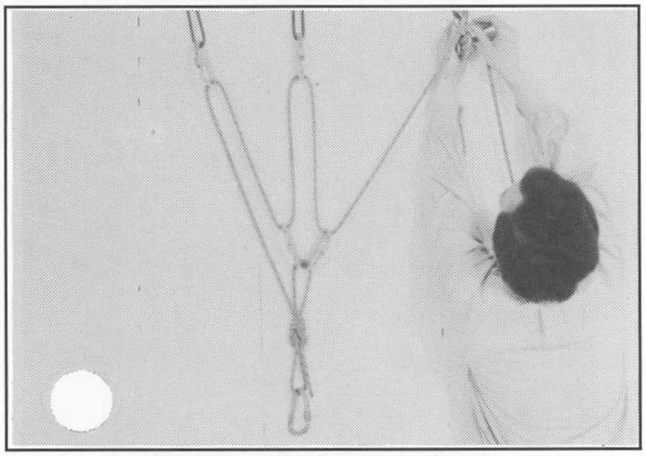


Plate 11-35. A multiple-point adjustable anchor. Step 3: Bring the standing rope back to the figure-of-eight.

Step 4 – Clip the standing part of the rope to the first carabiner (Plate 11-34) and bring it back to a second carabiner on the loop facing the anchors, not the main carabiner (Plate 11-35).

Step 5 – Repeat Step 4 to clip the standing part to each anchor point in turn, bringing it back to the loop facing the anchors each time, and using a new carabiner for each connection (Plate 11-36). Make sure that the loops are not twisted or crossed and cannot bind together.

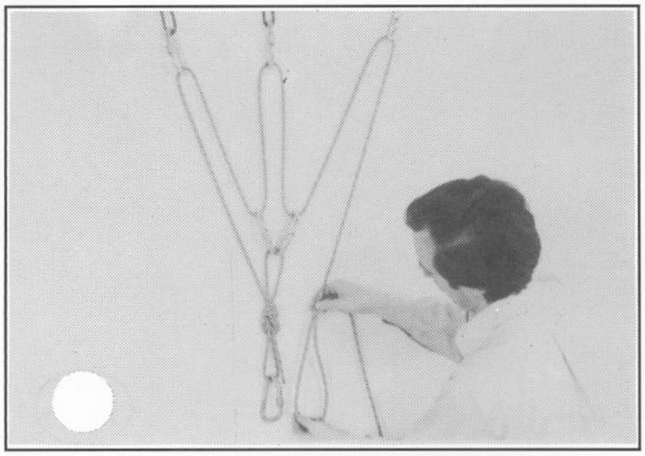


Plate 11-36. A multiple-point adjustable anchor. Step 4: Clip the standing rope to each anchor point in turn.

Step 6 – Before connecting the standing part to the figure-of-eight for the last time, put a little tension on it, and check that all angles are less than 90°. Make adjustments by pulling in or letting out the standing part.

Step 7 – Once satisfied, tie a figure-of-eight on a bight where you are holding the standing part (Plate 11-37) (you do not need the running end) and clip it to the main carabiner (Plate 11-38). This will keep the system more spread out and free flowing than if it is clipped directly to the lower loop in the figure-of-eight.

This system will distribute the load fairly evenly to all the anchor points and will even make some adjustment if the direction of pull should change (Plate 11-39). As with the two-point system, the equalizing part of the anchor system should be kept as short as possible to minimize the sudden jerk if one of the anchor points fails. Increasing the number of anchor points will also lessen the shock on the system if one gives way.

The method outlined above is also recommended for building a multiple-point non-equalizing system, because of the ease with which adjustments can be made to the connections between the anchor points. If a non-equalizing system is required, after completing Step 7, simply remove each of the bights clipped onto the inside loop, one at a time and without changing their length, tie a figure-of-eight in the bight and reconnect it. Such a non-equalizing system will be very satisfactory provided the direction of pull remains constant, but is less safe than the equalizing system if there are suspect anchor points or you are uncertain about the direction of pull.

If an anchor system is needed only as "insurance" to backup a "bombproof" anchor point, the first point can be connected to the backup by a long-tailed bowline with the tail running back to the second anchor, more or less in line, and fastened to it with a figure-of-eight or another bowline.

Never build an anchor system in which a single rope is clipped to two anchor points and tied back on itself to form a triangle with the load at the apex. Due to the pulley effect, this arrangement can put excessive loads on the anchor points, in some cases greater than the weight of the load they are supporting.

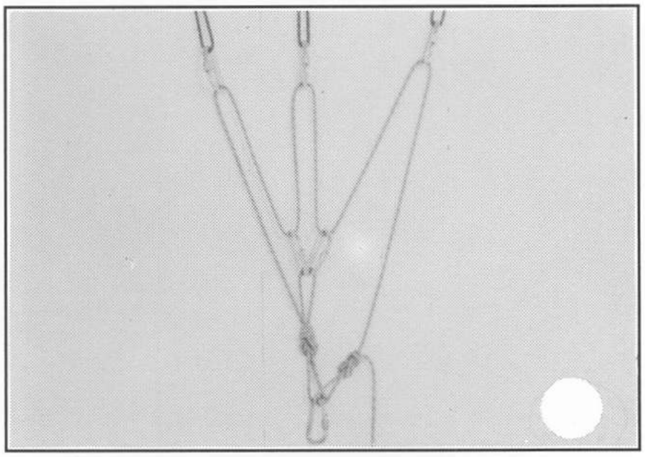


Plate 11-37. A multiple-point adjustable anchor. Step 5: Make a figure-of-eight on a bight where you are holding the standing end.

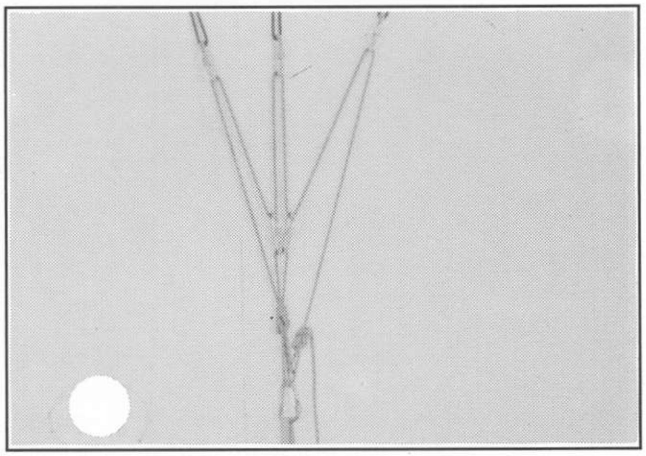


Plate 11-38. A multiple-point adjustable anchor. Step 6: Clip the figure-of-eight on the main carabiner.

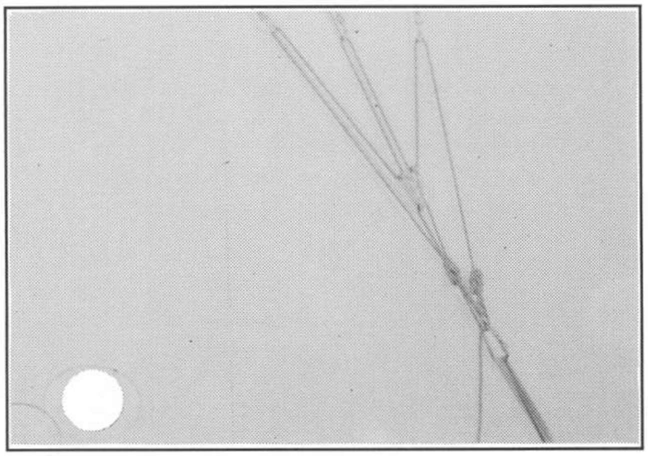


Plate 11-39. Adjustment of the load with change in the direction of pull.

CHAPTER 12

RESCUE OPERATIONS

TRAINING OBJECTIVES

Techniques for the recovery of accident victims stranded in inaccessible places were covered in the previous chapter. This chapter will deal with the rescue of victims trapped in vehicles as the result of an accident, in collapsed or burning buildings, in cave-ins on surface or underground, or in hazardous atmospheres. Each of these situations requires the use of specialized techniques.

Students will learn:

- **The use of basic extraction tools.**
- **The priorities in vehicle rescue.**
  - assessing the accident.
  - stabilizing wrecked vehicles.
  - triage; assigning priority of treatment to victims, according to their condition.
  - deciding which method will be used to extract victims from the wreckage.
- **How to gain access to a wrecked vehicle.**
  - extraction techniques.
- **Rescue procedures in burning buildings.**
  - the need for personal protection.
  - entry and communications.
  - controlling evacuation.
  - search procedures.
- **Rescue procedures in collapsed buildings and cave-ins.**
  - types of collapse.
  - improvised shoring.
  - removing debris.
- **Rescue procedures in hazardous atmospheres.**
  - sizing up the danger.
  - taking the right precautions against it.

RESCUE TOOLS

RESCUE BARS (Figure 12-1)

The long crowbar is probably the most valuable access tool in vehicle rescue work. It comes in many different designs, and can be used to pry open all types of doors and windows. It can also be used to lift or move heavy objects, or as a deadman.

The rescue bar (Halligan tool) is a solid steel bar roughly a metre (42 inches) long. It has a sharp pick and a separate blade on one end, both 10 centimetres (4 inches) long. The other end has a sharpened claw, which is slotted to fit hasps and locks.

The pry bar may be used as a slide hammer. There is a small button directly behind the blade at the back of the head which, when pressed, allows the interior bar to slide freely within the handle. The handle can also be removed and inserted into the side of the head.

AIR CUTTING GUN

At times it will be necessary to cut through the sheet metal of a vehicle body. The air cutting gun is a compact, lightweight, easily operated cutting tool designed to the specifications of the Emergency Squad Training Institute in Illinois. It is powered by compressed air supplied from a scuba tank through a 4.5-metre (15-foot) hose at a pressure of 2100 kilopascals (300 psi) and uses about 425 litres (15 cubic feet) of air per minute.

The gun kit includes three cutting tools: a T-type sheet metal chisel, and 18 and 38-centimetre (7 and 15-inch) flat chisels for cutting bolts and heavy struts. The air gun is designed to cut 0.6-centimetre (1/4-inch) mild steel plate, 1.9-centimetre (3/4-inch) mild steel bolts, safety door-lock bolts, auto door posts and sheet metal in a few seconds. It can also be used for forcible entry into sheet-metal buildings and ventilating ducts, and through fire doors and metal garage doors.

HAY-BALE HOOK

The hay-bale hook is used to remove vehicle windshields; a spring-loaded centre punch is used to shatter the side and rear windows. Care must be taken to keep broken glass away from victims; use an aluminized rescue blanket to protect them. Self-adhesive "Mactac" or any type of tape can be placed on the windows to hold the broken glass together.

AIRBAGS

Airbags are a versatile and invaluable tool in all types of rescue work. They work quickly, quietly and are relatively simple to operate. When used with scuba tanks they are portable and efficient. They are especially effective when used to:

- Release pinned victims from overturned vehicles.
- Move rubble in collapsed buildings.
- Bend steel bars, beams or doors to force entry or release trapped victims.
- Lift cylinders and irregular-shaped loads.
- Remove windshields, bend steering columns and remove seats in vehicles.
- Airbags will raise heavy loads on soft ground and even under water.

There are a number of different brands, shapes and sizes of bags, their lifting capacities range from 10 to 60 tonnes. They are made of reinforced neoprene with three layers of steel wire embedded in the neoprene on both sides of the bag, and are extremely puncture proof. Single or double control valves can be used to operate one or two bags at the same time. Air is

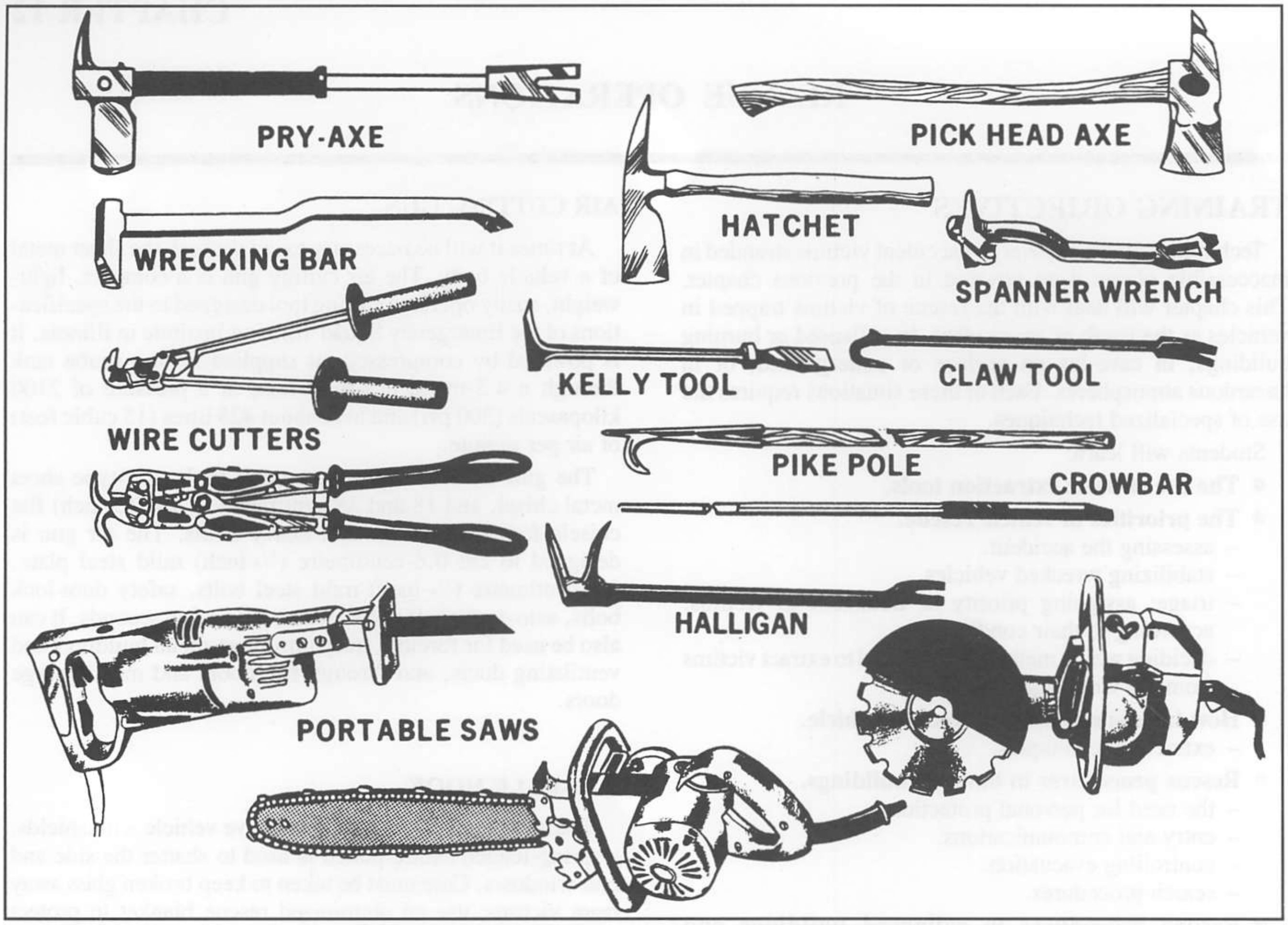


Figure 12-1. Examples of prying tools used in rescue work.

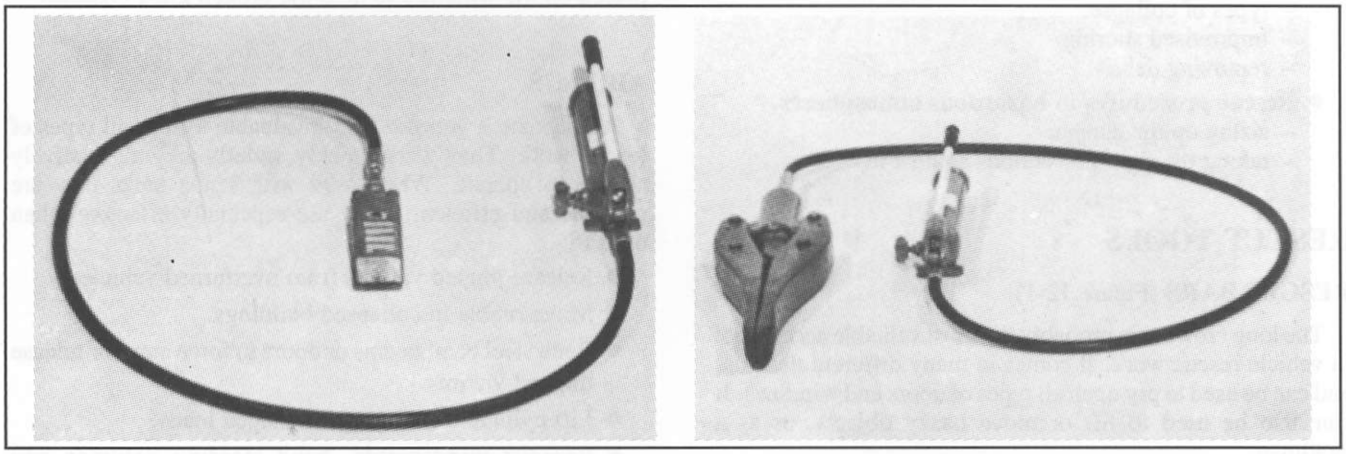


Plate 12-1. Examples of "portapowers". (A) A heavy-duty wedge set with P-400 pump and special extra-duty hose. (B) A heavy-duty spreader set with similar pump and hose.

supplied from a scuba tank at a working pressure of 800 kilopascals (116 psi). The airbags are only 2 centimetres ($^{3}/_{4}$ inch) thick when deflated, and can be easily placed under any object.

A basic system is usually comprised of two or three airbags of different capacity, a pressure regulator, dual controller/safety relief valve and air hoses. The regulator reduces the air pressure from the scuba cylinders to the desired working pressure. The dual controller allows good control of the bags while being inflated or deflated.

PORTAPOWERS

"Portapowers", hydraulically powered spreading wedges, are another tool that is used at almost every vehicle accident.

They are used to open doors, lift seats, move clutch and brake pedals, and lift vehicles off of victims.

The two most commonly used portapowers are the 4-tonne small wedge which opens to 7 centimetres (3 inches), and a 4-tonne spreader which opens to 28 centimetres (11 inches) (Plate 12-1). All units should be colour coded for quick identification; it may be necessary to use several portapowers at one time.

The wedges are pressurized by a hand pump. The pump is held between the operator's knees with the hose pointing downward so that the oil reservoir is kept above the pump assembly. The operator uses both hands and knees to push down the pump handle. A knob at the top of the pump assembly controls its operation. Turning the knob clockwise allows the wedge to be pressurized, turning it counterclockwise releases the pressure and allows the wedge to close.

POWER SPREADERS

A power spreader, "the boss" or "jaws-of-life" may also be used to provide additional lifting or spreading capabilities. These units develop 5 to 7 tonnes of force on the tips. The boss is powered by an air-over-hydraulic pump with the air supplied from a scuba tank. The jaws-of-life are powered by a hydraulic pump driven by an electric or gasoline engine. The jaws-of-life work very fast, require two people to hold them while in use and the compressors make a lot of noise.

COME-ALONG

A "come-along" is used to pull doors open, pull seats apart and pull the steering columns out of the way. It is an 1800-kilogram (4000-pound) hand-operated winch with 6 metres (20 feet) of 1/4-inch cable and a schiv block which allows you to use a two-part line (Plate 12-2). The hook on the end of the cable is kept secured to the body of the come-along when not in use. The unit has a tubular steel handle that is designed to bend before anything else on the come-along gives away.

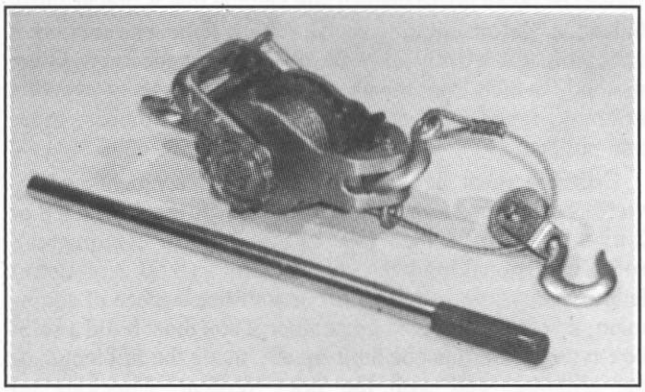


Plate 12-2. A "come-along".

CHAINS

Choker chains are essential when pulling with a come-along. Use only 9/32 alloy-steel chains. Sets can be made up to 1.5 and 3.5-metre (5 and 12-foot) lengths. Each one must have a slip hook attached at one end, a ring and grab hook at the other. The 3.5-metre (12-foot) chain has an oval ring and the 1.5-metre (5-foot) chain has a round ring for quick and easy identification (Plate 12-3). To shorten a chain, secure the slip hook to the vehicle frame, bring the grab hook to any point on the chain and secure it, then pull from the ring on the hook. Never stick the point of the grab hook inside a link of the chain; it may slip.

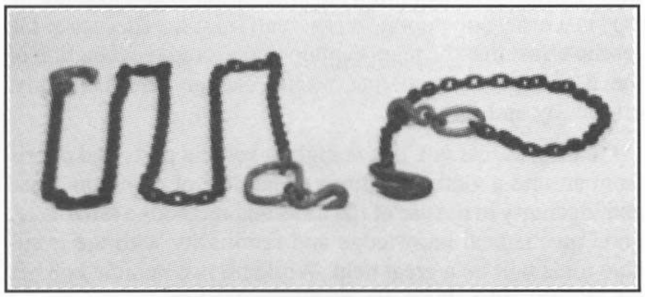


Plate 12-3. Standard-sized chains used in rescue work.

DOUBLE-ACTING SHEARS

Double-acting shears are suitable for cutting the metal in a vehicle, such as the steering wheel, roof posts, door posts, bumpers and seat frames. Cutting off the steering wheel column and the foot pedals is possible, using the bolt notch in the blades, however it is not recommended by the manufacturer. The high tension in these materials will cause the cut ends to come apart with such force that they may cause severe injury. The shears are operated hydraulically, either by a hand or a powered pump.

RAMS

Hydraulic rams of various lengths and capacities are available and can be used in many ways to lift, spread or pull, such as lifting a crushed vehicle roof off a victim. The rams can also be used in a number of ways to rescue trapped victims in other types of accidents.

OXY-ACETYLENE CUTTERS

Oxy-acetylene cutters are a quick and effective rescue tool at construction-site accidents, however, their use is fraught with dangers and not recommended for vehicle rescue operations. The head of the cutting flame produces fumes from the paint, oil, grease and upholstery in the vehicle, and the roof lining and upholstery will catch on fire. The cutting operation can only be carried out if the trapped victims are protected from the sparks and cutting flames with an aluminized rescue blanket. Carbon dioxide extinguishers cannot be used to control any fire that may break out as the gas will displace air in the passenger space causing oxygen deficiency. Only dry-chemical extinguishers should be used, and then only with extreme care.

WHEEL-SAW

A powered wheel-saw is also an effective tool at a construction accident. The sparks given off are not as hot as with gas cutting tools but may ignite gasoline fumes. The noise is also prohibitive in vehicle accidents.

RESCUE FROM VEHICLES

This section offers suggestions for the rescue of victims trapped in vehicles as the result of an accident. Rescue trainees are assumed to have a knowledge of first aid and no attempt will be made here to describe in detail the first aid measures that may be required in such accident situations. However, the immediate purpose is to save lives and a thorough knowledge of first aid is essential to all those taking part in a rescue operation. It is essential for the success of the rescue effort that the team captain make a rapid evaluation of the accident scene so that rescue can go ahead quickly, efficiently and safely.

Gaining access and disentangling vehicle parts and debris from around a victim require a great deal of common sense and ingenuity in the use of the tools and methods available. A good mechanical knowledge and familiarity with the available tools will be a great help. While no two vehicle crashes are exactly alike, there are many similarities.

Extricating victims from the wreckage, providing basic life support, and the potential hazards at the accident scene, place a tremendous responsibility and strain on the rescuers. It is essential that rescue crews follow their practiced procedures when responding to calls for help. Just as it is important to protect the victim from injury during the extrication process, the rescuers must also protect themselves. The use of safety goggles, hard hats and work gloves is mandatory, hard-toe shoes are also a very good idea. An injured rescuer delays the rescue operation, endangers the well-being of the victim and places an added burden on others in the rescue team.

PRIORITIES

The following is a suggested order of priorities, when rescuing trapped victims from vehicles and equipment:

IS THE AREA SAFE TO APPROACH?

Remember: "Fools rush in where angels fear to tread".

In a highway accident, control traffic, post guards and set out reflectors or flares. The rescue team should work closely with police officers. If possible they should allow the police to supervise and control the traffic situation.

Check for other dangers such as downed electrical power lines (*see* Chapter 10).

Lighting is critical. It is impossible to work in the dark. Good lighting can reveal unsuspected hazards and also victims that may have been thrown from the wreck. All rescue vehicles must carry floodlights capable of providing light at some distance from the vehicle, as well as a number of stand-up flashlights. A portable generator and a set of portable floodlights are always useful.

There will always be a certain amount of flammable liquid present at the scene of any vehicle accident, spilled or otherwise. It may be extremely dangerous. Gasoline vapours may be blown about by the wind, and as they are heavier than air, they will collect in hollows or low spots. An explosive mixture may be ignited by steel-clad boots or other steel articles striking a spark off a stone, a lighted cigarette butt carelessly dropped into the vapour, sparks caused by electrical circuits shorting out in the wreckage, or hot engine parts.

Post guards to prevent anyone from smoking or lighting a flame. It may be necessary to have all engines and ignition systems shut off in the surrounding area. Using tools could be disastrous if fumes or ignitable mixtures are present. An explosimeter (*see* Chapter 5) may be useful. Sealing putty, or a soft wooden plug, can be used to close a small leak in a fuel tank. If a small amount of fuel has been spilled, the first thing to come off the rescue truck must be the fire extinguishers. The silver AFFF, 10-litre ($2^1/_2$-gallon) pressurized water extinguisher is very effective for blanketing or sealing off any flammable liquid, or cooling off a hot engine. A larger fuel spill must be diked and pumped into tanks; the area can then be washed clean by the fire department.

Turn off the ignition in accident vehicles as soon as possible; you will usually find the switch remains on after a serious accident. If there is no leaking or spilled fuel or chemicals, and the vehicle wiring is not creating a short, do not remove the battery. If it is necessary to disconnect the battery, remove or cut the battery ground cable. Remember one spark may cause an explosion.

If a fire is already burning, victims must be removed to a safe distance immediately, with a minimum of immobilization, regardless of their injuries.

Hazardous chemicals may be a serious problem at the accident site. Chemical-carrying vehicles, vapour clouds or smoke may alert the rescuer that chemicals are a factor. The rescuers must put on breathing apparatus and protective clothing and attempt to identify the material involved. They must consult standard references on hazardous substances to determine the proper handling of the spilled chemicals.

CHECK THE STABILITY OF THE WRECKED VEHICLE(S)

Will they move in any way? Approach at a safe angle. Care should be taken not to disturb any vehicle that is precariously balanced. Before entering such a vehicle it must be anchored; chocking the wheels may be all that is necessary. Other methods which can be used include the use of wooden cribbing, spare tires, car jacks, cables and winches, ropes and pulleys.

Cribbing must be used at all vehicle accidents where victims are trapped under the wreckage. It is constructed of 2-by-4 and 4-by-4 inch (5×10 and 10×10 centimetres), soft, dimensional lumber, cut into 18-inch ($\approx$50-centimetre) lengths. Anytime you must lift or stabilize a piece of equipment, a vehicle or piece of machinery, you must build a solid box-type crib. It must be built square, using the full length of the cribbing, and with the sides vertical. Chocking up wreckage with pieces of cribbing lying on top of one another is unsafe. If the vehicle moves suddenly the cribbing may collapse and the vehicle may fall back onto the victim. If it is necessary to stack cribbing more than two pieces high, build a solid box-type crib.

Caution should be taken with a vehicle that is equipped with shock-absorbing bumpers. This mechanism may release at any time if it has been compressed in the collision.

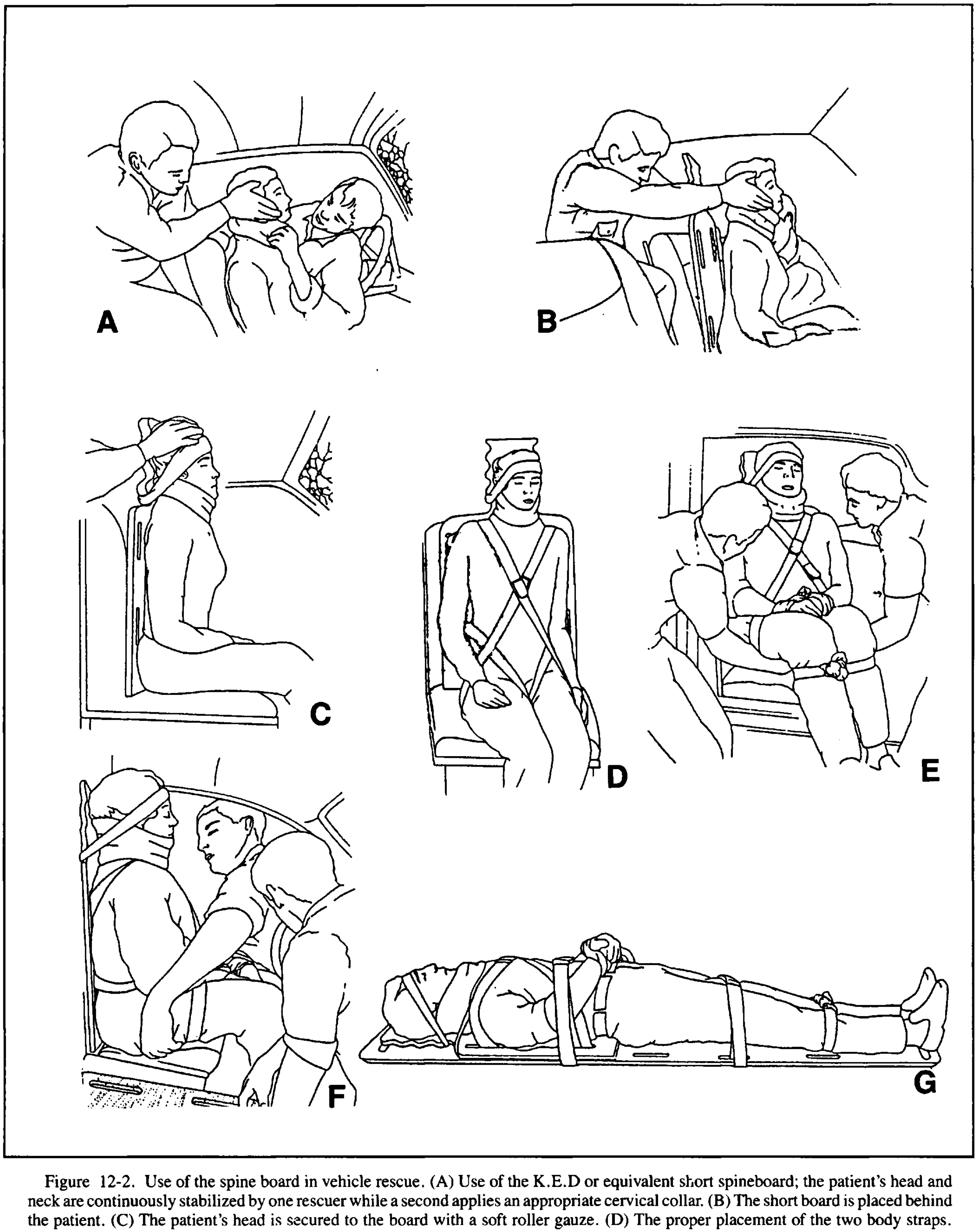


Figure 12-2. Use of the spine board in vehicle rescue. (A) Use of the K.E.D or equivalent short spineboard; the patient's head and neck are continuously stabilized by one rescuer while a second applies an appropriate cervical collar. (B) The short board is placed behind the patient. (C) The patient's head is secured to the board with a soft roller gauze. (D) The proper placement of the two body straps. (E) The patient is lifted out of the vehicle by two rescue workers. (F) A long spineboard used to help remove a patient. (G) The proper method of securing a patient to a long spineboard.

CHECK THE VICTIM'S CONDITION AND VITAL SIGNS

Rescuers must find out how many victims are involved and if they are all accounted for. Passengers may have been thrown clear of the vehicle and may be a considerable distance from the scene.

A high priority is to get a rescuer inside the vehicle to reassure the victims, administer first aid, talk to them and explain the rescue plan, especially when extrication tools will be used. Vital signs must be checked, and the most seriously injured must be treated first.

Any airway or breathing problems must be corrected and bleeding controlled. The rescuer can support the victim using both hands and body. Put an aluminized rescue blanket over the victim and tuck it in tightly. This blanket is made of aluminized gentex material and will protect the victim, in the event of a fire, by reflecting the initial fireball and heat. It will also protect the victim if the windshield has to be removed.

Rescuers often find some victims are already dead. If the victims are obviously dead, they must not be touched and the RCMP and coroner must be called. Obviously dead victims are those that have been decapitated, cut in half or so severely crushed that life could not be possible. In the absence of these extreme conditions, emergency first aid procedures must continue until medical aid arrives and the victim is pronounced dead.

DECIDE HOW TO EXTRICATE THE VICTIMS

The team captain must assess the situation, taking into consideration the type of vehicle, whether it is a pickup truck, a 300-tonne off-road haulage truck, payloader or bulldozer; the seriousness of injuries; and the number of victims to be evacuated. The captain must then decide what resources will be required for the rescue operation (for example, personnel, rescue equipment, ambulances) and in what order the victims are to be rescued.

Always bear in mind that all too often rescuers perform many different extrication procedures that would not have been needed if the situation had first been properly assessed. Removing a victim's shoes may free his feet; adjusting the seat may be all that is needed to free him completely. Why remove a stove-in door when all that is necessary is to remove the victim from the undamaged side? Rescuers must keep their "heads up" and be alert for changing conditions.

LIFTING THE VEHICLE OFF A VICTIM

Before the rescuer lifts any type of vehicle or piece of equipment off a pinned victim, the wheels must be chocked on the opposite side to the lift. Once the wheels are chocked, the rescuer may begin the lift. Wedges or spreaders may be used. The lifting device is placed on one side of the victim and a solid box-type crib built on the opposite side. As the vehicle is raised the rescuer must continue to insert cribbing so that if the lifting device fails, the vehicle cannot fall back onto the victim.

As the vehicle is raised it should never be further above the top of the crib than the thickness of a two-by-four. When the vehicle has reached the desired height, the rescuer can bring the victim out from under it. Remember to use a spine board.

Care must be taken to place the lifting device under the frame or other sturdy part of the vehicle such as a bumper. This will ensure that the vehicle does not slip off the lifting device; this rule is not as critical when using airbags because the bags are large and do not exert force on a small area. **Always make the lift slowly and do not lift the wreckage higher than is necessary to remove the victim. Make sure the wreckage is stable before removing the victim.**

RESCUE, TREAT AND TRANSPORT THE VICTIMS TO MEDICAL AID

Never pull victims from a vehicle unless their lives are further endangered by leaving them where they are.

Great care must be exercised while gaining access to the victim, as the tools are closest to the patient. Heat, noise and force should be kept to a minimum. Every possible precaution must be taken to avoid any further injury. After the victim is reached, additional first aid should be provided as other parts of the body become accessible for treatment.

If bones are broken, they must be correctly splinted before the victim is moved. If there is any possibility that a victim's neck or back may be dislocated or fractured then the victim must be treated as though he has a spinal fracture. For a neck injury, a cervical collar, a Ferno K.E.D. extrication device and a long spine board must be used to move the victim (Figure 12-2). The rescue vehicle should carry all the necessary equipment.

RESCUE FROM BURNING BUILDINGS

A thorough, planned search for victims should be conducted at every fire. Moreover, all firefighters should be able to conduct a search if the need arises. All personnel should be able to conduct a search if the need arises. All personnel should realize that the safety of firefighters engaged in search is their responsibility; they must constantly be aware of the presence of these men. For instance, men operating a line on the floor must be aware that firefighters will be searching the floors above for possible victims. If the men on the line cannot control the fire and are forced to retreat from the building, the firefighters above must be warned so that they can take appropriate action. Men assigned to laddering duties must also be aware that a search is in progress since they may have to place ladders as additional exits for search personnel and victims.

Since search is an overall responsibility, it should be performed according to an efficient standard procedure that is safe for the firefighter. The procedure should be simple and straightforward so that one firefighter can substitute for another at any point in the search. It should include a simple, easy-to-follow search pattern that ensures that the search begins where there is most danger to occupants.

Normally, occupants closest to the fire are in the most danger, whether they are on the fire floor or the floor above. Those on the fire floor will be affected by radiant heat, smoke, and gases and those above, by convected heat, gases, smoke, and hot air. Occupants who are two or more floors above the fire (and especially the top floor) may be endangered by smoke and heat that have been channeled up through the building. Thus, firefighters must begin both search and ventilation operations quickly, while firefighters attack the fire.

SEARCH DUTIES

It is obvious that a number of operations must be carried out simultaneously (or as nearly so as possible) in a rescue situation. While following a standard search procedures, firefighters should perform the following duties (of course, the first is the most important):

- Locate and remove trapped occupants
- Ventilate where needed
- Temporarily prevent extension of fire by closing doors and windows
- Check for interior and exterior fire extension
- Help locate the seat of the fire, when necessary.

STANDARD SEARCH PROCEDURE

The best way to see the value of a standard search procedures (and standard search pattern) is to look at a typical search. This section supposes a fire on the first floor of a two-storey dwelling in a large kitchen and dining area. Standard procedures and the search pattern described apply to all buildings.

Search begins immediately. Companies arriving at the scene would immediately size up the fire situation. Engine companies would obtain water and get attack lines into the house, to cut off the fire and then hit it directly. The men on the lines, by getting low, can probably see some clear area over the floor, and they check for victims near the fire. But the stairway and the upper floor will be full of smoke and gases. An immediate attempt should be made to get the firefighters with self-contained B.A. to the upper floor. If the area is tenable, they can begin searching for victims. If the area is untenable because of the intense heat, ventilation must begin from the outside. Windows on the lee side should be knocked out first. One man with a short ladder can quickly knock out enough second-floor windows to make a big difference.

Search pattern. As soon as the second floor is tenable, the search will begin. According to standard procedure the most dangerous area is the first place to be searched, that is directly over the fire.

On reaching the top of the stairway, the search personnel will have to turn in one direction or the other to get over the fire. This turn sets up the basic search pattern. As the search proceeds, these men will **keep turning in the original direction** as they go in and out of rooms. For instance, suppost that a man engaged in the search turned left at the top of the stairs to move down the hallway and get over the fire. Then, according to the pattern, he turns left again to move into a room. On coming out of the room, he again turns left and moves to the next room. He continues on this left-turning path until he has worked his way around the hall and back to the stairs.

Other men should follow the same pattern. Whenever possible, at least two men should be assigned to search in an area. As they proceed with the search pattern, they should check each room that is not marked as having been searched (as discussed below). They should attempt to keep track of each other by tough, sight, verbally, and by listening for the sound of the other man's mask. Each should be alert for a call for help from the other.

Areas to be searched. Corridors and halls should be checked thoroughly, as should the open area of each room. In addition, bathrooms, closets, and the spaces behind large chairs and under beds should be checked. People often seek protection in these places. The areas near windows should be checked for victims overcome while attempting to reach a window. Everyone engaged in the search should carry a tool such as an axe, Halligan, or claw tool, with which these areas can be probed and which can be used for venting and forcing locked doors. Each man should carry a handlight.

If the fire has extended into a room, that room should be shut to isolate the fire. Standard procedures for engine companies should include a line over the fire for just this situation. With a stream available, there is a better chance for the search to proceed quickly and safely.

If a room is not involved with a fire but contains heat and smoke, it should be vented. Its door should be opened, and its windows opened or knocked out, to clear the area for a more effective search. Windows in hallways and corridors should be opened or removed.

Indicating that a room has been searched. There should be some standard way of indicating that a room has been searched so that there is no duplication of effort, at least not in the initial search operation. When the door to a room is to be left open to vent through the room, an effective method is to place a piece of light furniture in the doorway. A chair, footstool, end table, lamp table, or anything that can be quickly dragged or carried into position will do. The piece should be set on its side so that the legs are pointing out of the room since there is little chance that a piece of furniture could be knocked into such a position accidentally. This is quickly done and easily recognized by other search personnel.

If fire has extended into a room, or if there is danger of fire extending into the room, the door must be closed after it is searched. Then, a piece of cloth should be placed against the door jamb, at about doorknob height, and the door pulled shut against it. The corner of a bedsheet, a pillos case, a tablecloth, or an item of clothing can be used for the purpose. In this situation, a line should be called for immediately.

Some departments have had success with placing tags on the doors of inspected rooms, apartments, and offices. Whichever of these types of search indication is used, firefighters do not have to enter a room to find that it has already been searched.

Other structures. The standard search procedures and the search pattern described here apply to other buildings as well. The search pattern may be used in a single-storey dwelling, an apartment house, or an office building.

Once they turn off a corridor into an apartment or office, the firefighters engaged in the search should follow the same pattern within the unit. When they leave the unit, they should retain the pattern in the corridor and when they enter the next unit. If a man enters an office unit with a right turn, he places his right side to the wall and must then keep his right side to the wall as he works his way through the unit and back to the door leading to the hall. If he enters with a left turn, he should keep his left side to the wall as he searches the unit and works his way back to the door. When he leaves the unit, he must retain this pattern in the hall and in entering the next office unit.

It is important that search personnel leave an office or work area through the same doorway used to enter it. Otherwise, a part of the unit containing trapped victims may be overlooked. If fire conditions force a man to leave by a different door, he should report this fact immediately. Hoselines should be quickly advanced to the area and the unit searched thoroughly.

The larger the structure, the more men must be assigned to search and rescue. First alarm assignments must be adjusted to ensure adequate response in each area of a department's territory. Search and rescue are firefighter functions; engine companies should be free to direct all their efforts to advancing hoselines in support of rescue operations. However, where truck companies do not respond (or do not have sufficient manpower), engine company personnel must carry out search and rescue operations. With a standard procedure and proper training, assignments can be adjusted to cover any situation.

SEARCH TECHNIQUES

Search personnel must work as quickly as possible, but they must also be careful to avoid unnecessary injury to themselves and victims. This is especially true when searching near or above the fire, because although the fire may have extended into such areas, it may be hidden by doors to rooms or to sections of the building.

Doors. Before any door is opened it should be checked to see if it or its knob is hot. A very hot knob usually indicates that there is fire on the other side of the door. Some heat in either the knob or the door probably means that the room beyond the door is full of smoke and gases, but not fire. The gases could ignite suddenly (and explosively) if the door is opened quickly. In such situations, the safest course is to first determine which way the door opens. Most doors between hallways and apartments or offices open into the unit — that is, away from the entering firefighter. Inside the unit, doors may open in either direction. If the hinges are on the outside, then the door opens out toward the firefighter. Some modern doors with flush, hidden hinges give no indication of which way they open. However, if the door jamb does not cover the edge of the door, then the door opens out. If the edge of the door is covered, it opens into the unit.

Doors that open out are the most dangerous to firefighters, but they must be opened during the search. If an outward-opening door shows some heat, the firefighter should get low and place his full body weight against the door. Then he should release the lock slowly and allow the door to open slightly. As the lock is released, the firefighter may feel a strong push against the door from the inside. This indicates that the room is full of smoke and gas, possibly along with fire. The firefighter should close the door immediately and call for an attack line, and the door should not be opened again until the line is in position. The same action should be taken when there is no push against the door, but the room is seen to be full of fire.

If the door opens into the room, the lock should be released slowly and the door eased in. Again, if there is a strong push against the door, or if the room is heavily involved with fire, the door should be shut and an attack line brought into position. Otherwise, the unit or room may be entered and searched.

Victim. Occupants of a fire building will naturally try to escape through doors, windows, fire escapes, halls, and stairways leading out of the building. Firefighters should look for overcome victims near and in such places. In particular, firefighters must be sure that the push against an inward-opening door is due to smoke and gas, and not a victim lying against the door.

The pressure of smoke'and gases is distributed evenly over the entire door. It is felt from the moment the door is first opened. If a victim is lying against the door, the pressure will be felt more at the bottom than the top. If the victim is near the door, it will open easily at first, and the firefighter will feel a bump as the door hits the victim.

When a firefighter finds both conditions — indicating that a victim is lying near the door of a room filled with smoke and gas — he should attempt to open the door enough to remove the victim and then shut the door. Just getting the victim out of a smoke-filled room and into a less-charged hallway may mean the difference between life and death. If necessary, the firefighter should immediately call for help, an attack line, or whatever is needed to get the victim out of the unit.

When a door opens inward easily at first and then contacts an object, the firefighter must assume that there is a victim just inside the door. Few people place their furniture so that it blocks doorways. The door must be opened and the victim removed, but the firefighter should not beat on the door with tools, body, or boots since this will only add to the victim's injuries as the door is slammed into him. Instead, the firefighter should drop down and probe around the inside with tools or his hands to find the victim. If possible, he should get the victim away from the door, open it, and get the victim out of the room.

Great physical effort is often required to move a victim away from a door. The firefighter must work from an awkward position with a door between himself and the victim and must move a dead weight. If he needs help, he should call for it quickly.

If enough firefighters are available, victims should be removed from the building while the search continues; otherwise, victims should be removed and the search resumed. In larger structures, this latter course of action can cause too much delay, and in some cases, it may be better to get the victim into the hallway, vent the hallway, and — if possible — vent the room or unit and continue the search. This is especially effective if the victim is found near or at the door and he is still breathing.

If the victim is found deep within an apartment or a large room or office, the best courst of action may be to punch through a partition into an adjoining apartment or room. The victim can then be moved into a less-charged area and the search resumed.

Visibility. When smoke reduces visibility during search operations, firefighters should stay low and move quickly on hands and knees. The hands and lower legs should be used to feel for victims and for obstructions or holes in the flooring.

In hallways and corridors, the walls can serve as directional guides. As search personnel feel along hallway walls, the locations of doors will become obvious. Inside the rooms of apartments and office suits, the hands-and-knees position will keep firefighter from tripping over furniture and other obstacles and will help in locating victims.

Windows should be opened or removed as they are encountered. This will help relieve the visibility problem and make it easier for search personnel to find and get to victims. It will also reduce the danger (from heat, smoke, and gases) to both firefighters and victims.

RESCUE FROM CAVE-INS

A growing number of fatalities and serious injuries at mining operations are resulting from cave-ins in surface excavations, sloughing stockpiles and similar causes. Around mines and gravel pits, where loose material is often stockpiled or stored in bins or hoppers and will be drawn down from below, there is always a danger of workers being trapped by falling into a draw-point or by sudden collapse of a hang-up. Any excavation in loose unconsolidated material, for example, backhoe trenches, represents a similar hazard until shoring is in place.

Assuming victims are not completely buried the immediate priority is to ensure their supply of air; if no other means are available, air can be directed to a victim through a simple garden hose. Once the air supply is secured, continued rescue operations depend on making the site as safe as possible. A rescue drum (Figure 12-3), lowered over the victim with ropes, will provide protection from further cave-ins during the rescue operation; a second drum can be added if more height is needed. As soon as the drum is secured in place, work quickly to remove any material around the victims's chest or abdomen that may be restricting breathing. Oxygen should be given as soon as possible and if breathing has stopped, mouth-to-mouth resuscitation must be started immediately.

It is only common sense that heavy equipment must not be used for removing loose material until the exact number and location of victims is known. Similarly picks and other sharp tools should not be used in the search for victims, or only used with great care. Debris should be removed from the cave-in in buckets, baskets or wheelbarrows and dumped a safe distance away so that it cannot fall back into the hole.

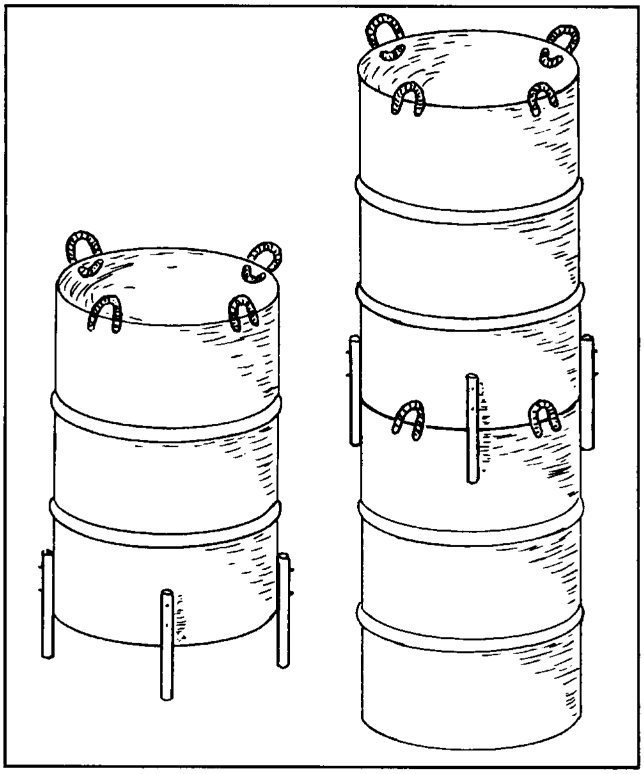


Figure 12-3. A rescue drum used for protecting cave-in victims while rescue is in progress.

SPECIAL HAZARDS OF WINTER CONDITIONS

TRAINING OBJECTIVES

Canadian mines, particularly open-pit mines in the north, have unique hazards arising from the harsh winter conditions. The problems associated with driving on icy roads, walking on slippery paths or ice falling from roofs can usually be overcome by using the right equipment or by removing the hazard, and should not normally become a concern for rescue crews. However mine rescue teams should be aware of the special dangers associated with winter travel over frozen lakes and rivers or through avalanche-prone areas, the effects of wind chill and the risk that accident victims may be overcome by hypothermia. This chapter will provide a basic understanding of:

- **Avalanche hazards.**
- **Avalanche search and rescue.**
- **Hazards of ice-travel.**
  - assessing ice conditions and safe load limits.
- **Treatment and prevention of hypothermia.**

AVALANCHE HAZARDS

Avalanches are a leading cause of fatal accidents in the mountains of British Columbia. They are a complex and poorly understood phenomenon, and are commonly unpredictable. They occur most frequently, and are generally larger, in areas of heavy snowfall, but may occur anywhere given the following conditions:

- Snow accumulates on a moderate to steep slope (30° to 45°) with few trees or other obstructions; avalanches rarely start on slopes steeper than 45° as snow sloughs off continuously rather than accumulating.
- The snow has not compacted and its shear strength is minimal.
- A layer of snow crystals has been altered to globules of ice, as a result of pressure or freezing and thawing, in effect creating a bed of icy marbles on the slope.
- An external event triggers the slide; this might be a new snowfall, the wind, the collapse of a cornice, an earth tremor, an explosion, or the movement of men or animals.

AVALANCHE TERRAIN – TERMINOLOGY

The **avalanche path or site** is the specific area through which the snow moves. It contains:

- The **starting zone** or point of origin, where the unstable snow first breaks away. An avalanche path may have several starting zones separated by rock ridges.
- The **track** or zone of transition, below the starting zone, where the avalanche accelerates and may reach a steady speed.
- The **run-out zone** where the avalanche decelerates and finally comes to rest. It can be divided into a zone where the bulk of the snow is deposited.

An **avalanche area** contains one or more avalanche paths. Their boundaries are determined by the terrain, but caution should be exercised in defining boundaries; large avalanches often over-ride obstacles.

It is always safest to avoid travel through avalanche areas, but if this is not possible, try to cross above the starting zone or below the runout zone. If crossing a known avalanche track is unavoidable, try to do so early in the morning before the sun has melted overnight frost. If a slide starts while crossing the track, do not expect to outrun it. It has been estimated that the Granduc avalanche, in which 26 men lost their lives, contained 50 000 tonnes of snow moving at a speed of 160 kilometres per hour.

TYPES OF AVALANCHE

Two kinds of avalanche are commonly recognized:

- **Loose snow avalanches** may consist of dry powder snow or wet snow. **Dry snow** avalanches are most common in winter after storms and rare in spring or summer. **Wet snow** avalanches consist of heavy, wet, sun-heated or rain-rotted snow, or wet new snow and are most common in spring and summer, particularly on south-facing slopes. These avalanches:
  - start from a point.
  - are set in motion progressively.
  - require snow with poor cohesion, similar to that of dry sand.
  - are usually confined to surface layers and therefore relatively small.
- **Slab avalanches** occur when a slab of fairly cohesive layers of snow, poorly bonded to the snow underneath, breaks off along a fracture line. These avalanches are by far the most dangerous; they:
  - are set in motion simultaneously, over a large area.
  - may start in either shallow or deep snow layers.

FAILURE OF A SNOW SLAB

Layering is the most important property of the snowpack with respect to the formation of slab avalanches. An avalanche will start when the weight of the slab and the strength of the snow are closely balanced and the relatively small force of a triggering mechanism will upset the balance. The initial failure is usually by shear in a weak layer or between two weakly bonded layers, followed by the slab breaking away at the crown. The fracture line at the crown is often some distance from the point of initial failure. Once the slab has failed and the intial static friction has been overcome, the slab accelerates rapidly and may break up into smaller slabs.

SAFETY AND SURVIVAL IN AVALANCHES

The successful rescue of a person buried in an avalanche very often depends upon actions taken by unburied survivors. Teams carrying out rescue operations in an avalanche area must be mentally prepared for the possibility that they too may be overtaken by an avalanche.

If **crossing an avalanche track** cannot be avoided, take the following precautions:

- Select the shortest possible route high on the slope or low in the run-out zone.
- Plan an escape route.
- Wear mitts and hats; tighten clothing; loosen packs, wrist loops on ski poles and safety straps on skis.
- Assign a spotter at the top and bottom of the track and agree on a warning signal.
- Cross quickly, one person at a time if the crossing is narrow, otherwise at wide intervals.

If **caught in an avalanche:**

- Call out to attract attention.
- Discard packs, skis, snowshoes or other equipment.
- Fight to stay on surface; kick and make swimming motions.
- Try to steer to the edge of the avalanche; roll sideways and try to grab rocks or trees.
- Remember the terrain; be prepared for falls over cliffs and collision with trees in the run-out zone.
- As the avalanche slows, make a final strong kick toward the surface just before it stops moving; inhale deeply and try to make a breathing space in front of your face.
- Stay calm and keep your mouth closed.
- Push one arm up toward the surface, but do not try to fight your way out of stationary snow unless you can see light above you.

Proper **action by unburied survivors** may save lives. Spotters, and others that have crossed safely or are still waiting to cross, must:

- Watch those caught in the avalanche from the time they are first trapped until they disappear from sight. Note the place where victims were last seen and mark it if possible.
- Count survivors; establish how many people are missing.
- Assess the risk of a second avalanche; post spotters if necessary and feasible.
- Determine where victims are most likely to be buried by following the flowline down from the point where they were last seen. Places where the avalanche flow may have been disrupted by trees or rock outcrops, or by crossing roads or other obstructions, are prime targets.
- Look for equipment and clothing on the surface and dig around them. Mark the location.
- Carry out a search by radio transceiver; listen for victims' voices.
- If this is unsuccessful, probe the likely burial area, using reversed ski poles, blunted ice axes or anything else on hand.
- Decide whether or not to go for help. Remember, half of all victims will die in 30 minutes, many within 5 minutes. After 2 hours a victim's chances of survival are very low.
- Organize a probe line and mark probed areas. Keep searching.

AVALANCHE RESCUE

Rescue teams called in to aid in the search for avalanche survivors should use the following procedure:

- Count off and list the members of the rescue team.
- Check all rescuers have warm clothing. Check the equipment list: probes, shovels, a first aid kit and a fully operational radio transceiver (check it before starting out) are essential. Is there anything else you might need?
- Travel to the accident site under the direction of the team captain and using all travel precautions already described. Note the time of arrival at the accident site.
- The team captain will take charge of rescue operations; follow his instructions.
- Cache equipment off the slide and downwind from it, so as not to interfere with the work of search dogs if they become available. Do not land helicopters on the slide.
- If survivors have not already done so, set up a coarse probe line. Searchers should be spaced a foot apart, with their feet a shoulder-width apart. Each searcher probes once between their feet and then moves ahead a short pace and probes again. Keep the line straight.
- Maintain a roving search and probe line, and brief additional searchers as they arrive on the scene. Keep track of new arrivals.
- Continue the search until there is no possibility of survivors or until search dogs arrive.
- On the arrival of search dogs, the dogmaster will take control of the rescue operation. Follow his instructions.
- Once the slide has been probed from top to bottom, and if no dogmaster has taken control of the search, reorganize the probe lines at the bottom and repeat the coarse probe process.
- Resort to a fine probe if this fails and prepare for a long operation.
- Replace tired rescue workers with fresh searchers as they arrive.
- Keep in radio contact with the base rescue co-ordinator and send tired searchers back to base in small groups, with a designated leader. Keep track of who is leaving.

When a **victim is found:**

- Do not remove the probe but dig quickly and carefully down along it.
- As soon as the victims's head and chest are uncovered, apply mouth-to-mouth resuscitation.

- Protect the victim's body from further exposure to cold as soon as possible and treat for hypothermia. Many victims will also have head and internal injuries; check, apply first aid and evacuate to a hospital as quickly as possible.

At the conclusion of rescue operations send rescuers back to base in small groups, each with a designated leader. Make sure all searchers and equipment are accounted for.

TRAVEL ON FROZEN LAKES AND RIVERS

Some mining operations in remote northern locations use ice roads built on frozen lakes and rivers for hauling in heavy equipment and bulk supplies during the winter. In many parts of northern Canada it is customary to undertake surface exploration programs during the winter when ice roads and airstrips can be used to service areas that are inaccessible during the summer and the ice on lakes and swamps is thick enough to support the weight of drilling equipment.

It is critically important to evaluate the strength of the ice before moving vehicles or equipment onto it. Expensive items of heavy equipment have been lost and aircraft severely damaged when the strength of the ice has been misjudged. The thickness of the ice must be tested frequently, using an auger drill. Table 13-1 indicates the weight that will be supported by varying thicknesses of clear, blue lake-ice, provided the load remains in motion. **Clear, blue river-ice, with moving water beneath it, is not as strong as lake-ice;** loads should be reduced by at least 15 per cent. The strength of slush ice varies with the degree of compaction, but assume it will only carry half the load supported by clear, blue ice of the same thickness. Cracks in the ice also severely reduce its ability to support a load. The figures given in Table 13-1 **do not apply to stationary loads.**

TABLE 13-1
STRENGTH OF CLEAR, BLUE LAKE-ICE

Thickness of ice (cm)	Permissible Load
5.0	One person walking on foot.
7.5	A small group, walking in single file, at least a metre apart.
19.0	Passenger car – 1800 kilograms gross.
20.0	Light truck – 2250 kilograms gross.
25.0	Medium truck – 3200 kilograms gross.
30.0	Heavy truck – 6.5 to 7.5 tonnes.
40.0	Small tractor – 10 tonnes.
50.0	22.5 tonnes.
60.0	40 tonnes.
75.0	65 tonnes.
90.0	100 tonnes.

Ice will sag under the weight of a load. If the load is a moving vehicle, the sag becomes a wave traveling ahead of it. The faster the vehicle moves the steeper the wave will become. Excessive speed will result in cracks developing, and possible loss of the load, even though the thickness of ice was theoretically capable of supporting it. The depth of water beneath the ice also affects propagation of the wave; safe maximum speeds increase with the depth of the water, but if this is not known, assume it is shallow. Maximum safe speeds for varying water depths are shown in Table 13-2.

TABLE 13-2
MAXIMUM SAFE SPEEDS DRIVING ON ICE

Depth of Water (m)	Maximum Safe Speed (km/h)
0.3	3
0.6	5
1.2	8
2.5	11
5.0	16
10	22
20	30

If cracks develop under your vehicle while you are driving across ice, **slow down and be ready to jump;** flotation jackets should always be worn when working on ice. Figure 13-1 shows the percentage reduction in speed required to negotiate cracks parallel, oblique and at right angles to the direction of travel.

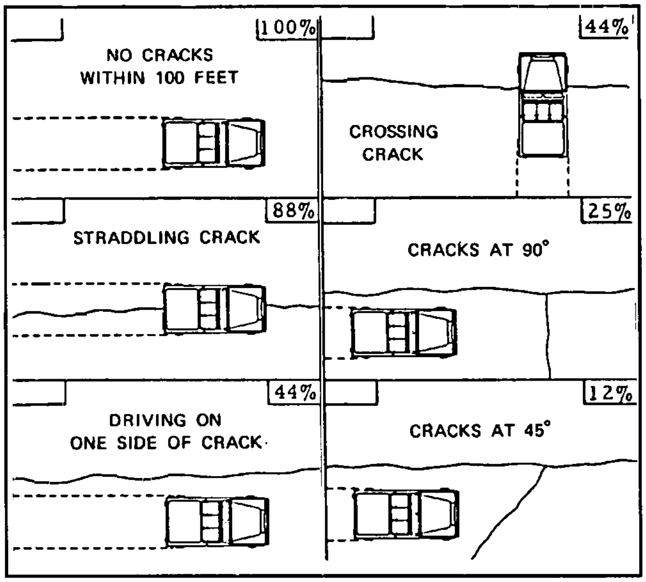


Figure 13-1. Safe driving speeds for driving on ice when lateral, transverse and oblique cracks appear.

HYPOTHERMIA

Hypothermia, sometimes known as exposure sickness, is the leading cause of death to people in the outdoors. Defined as a condition of lowered internal body-core temperature caused by overexposure to a cold environment, it can develop very quickly if proper precautions are not taken. Hypothermia results from chilling by cold wind or water such that the body loses heat faster than it can produce it. Once cooling begins the body temperature falls steadily and unconsciousness usually occurs when the deep-body temperature reaches 32°C (89.6°F), 5°C below the normal level. Cardiac arrest, the common cause of death, will occur if the internal temperature falls below 30°C (86°F). The onset of hypothermia is often accelerated if there is a deficiency of energy-producing food in the body, but the principal cause is inadequate clothing. The use of drugs or alcohol also accelerates the onset of hypothermia and increases the risk of fatality. The major difference between the onset of hypothermia on land and in the water is the time scale; it develops faster in water as heat is conducted away from the body 25 times faster than in air at the same temperature.

Hypothermia can occur anywhere that the environmental temperature is low enough to reduce the inner-core temperature of the body to the danger level. The most common causes on land are a combination of bad weather, associated with physical exertion and inadequate clothing. This combination of circumstances can very easily occur when traveling through mountainous terrain on foot; it is easy to pass from a calm and sunny valley to a wind and rain-swept ridge in just a few hours. Similarly you may feel very comfortable in an air temperature of 5°C (40°F) on a calm day. If the wind increases to 40 kilometres per hour, which can happen very quickly, the effective temperature is reduced to a cold − 10°C. Man-overboard accidents account for the majority of hypothermia-related deaths in water, but ice-travel also represents a special hazard. Hypothermia accidents generally occur when the air or water temperature is in the range − 1° to 10°C (30° to 50°F).

PREVENTION OF HYPOTHERMIA

The old adage that an ounce of prevention is worth a pound of cure is particularly true of hypothermia. With the exception of cases involving bodily injury, most hypothermia accidents could have been prevented. The most important thing to remember is that hypothermia can occur at any time, summer or winter, if the temperature conditions are such that the body cannot maintain its heat.

The best defense against hypothermia is to avoid exposure and be prepared. Wearing the right clothing is critically important. Some types of wet clothing will extract heat from the body up to 200 times faster than dry clothes. Cotton material provides little protection whereas natural wool retains reasonably good insulating qualities, even when wet. An uncovered head can account for up to 60 per cent of total body-heat loss in cold weather – carry a woollen toque or a cap.

Observation of the following basic rules will prevent most hypothermia accidents:

- Dress appropriately. Carry raingear, extra dry clothes, high-energy food and waterproof matches or a lighter.
- If you are the leader of a party of novices, explain the basic rules of trail safety and ensure that they are strictly applied.
- If anyone in the party is inadequately dressed, point out the potential danger, before setting out; you may save a life.
- Travel at the speed of the slowest member of the party.
- Take short rests at frequent intervals; distribute candy or other high-energy food.
- If potentially dangerous conditions are encountered, and it becomes apparent that some members of the party are not properly equipped, turn back or head for shelter, build a fire and concentrate on making your camp as secure and comfortable as possible.
- Keep watching all members of your party for signs of fatigue or discomfort. It is far better to abandon the trip than risk losing a life.

SYMPTOMS OF HYPOTHERMIA

Fortunately the approach of hypothermia is noticeable by its easily visible symptoms and its advance is marked by recognizable stages. If warning signs are heeded and countermeasures taken immediately, tragedy can be avoided. Early indications of the onset of hypothermia are:

- The victim feels cold and must exercise to warm up.
- The victim starts to shiver and feels numb.
- Shivering becomes more intense and eventually violent and uncontrollable. Speech becomes more difficult, thinking becomes sluggish and the mind starts to wander.
- Shivering decreases and muscles start to cramp. Exposed skin may become blue or puffy. Thinking becomes very fuzzy and appreciation of the seriousness of the situation is vague and may be totally lacking, but victims may maintain the appearance of knowing where they are and what is going on.

If preventative measures are not taken, advanced symptoms will soon become apparent:

- The victim will become irrational, lose contact with what is going on and drift into a stupor. The pulse and respiration rates slow down.
- The victim no longer responds when spoken to and slides into unconsciousness. Muscles stiffen, most reflexes cease to function and the heartbeat becomes erratic.
- Finally the heart and lung control centres in the brain stop functioning. The victim is dead.

TREATMENT OF HYPOTHERMIA

Healthy people who are alert and aware of the danger can help themselves during the early stages of hypothermia, but once their minds start to wander they may not realize what is happening to them and may need help. If their condition deteriorates further, they will definitely need help. If a member of your party shows any of the early symptoms – uncontrollable shivering, slow slurred speech, memory lapses, incoherence, fumbling hands or stumbling gait, drowsiness or inability to get up after a rest – they are in trouble and need your help. **Do not take NO for an answer; believe the symptoms, not the victim.** Even mild symptoms demand immediate treatment.

- Get the patient out of the cold, wind, rain or snow. Improvise a shelter and build a fire.
- Strip off all wet clothes.
- If the patient is only mildly impaired, give warm non-alcoholic drinks and get him into dry clothes or a warm sleeping bag as quickly as possible. Rocks warmed in the fire and placed near the patient will speed recovery.
- If the victim is semiconscious or worse try to keep him awake or revive him by giving warm drinks. If a sleeping bag is available, keep the patient stripped and

put him in the bag with another person, also stripped; skin-to-skin contact is the most effective treatment. If you have a double sleeping bag, or two bags to zip together, put the patient between two warm people.

COLD-WATER SURVIVAL

As already indicated, the onset of hypothermia is much quicker if the victim is emersed in cold water and is therefore a significant hazard to boaters and anyone working on frozen lakes and rivers. Scientists have studied the effects of immersion of the human body in cold water under conditions typical of boating accidents on Canada's large lakes and coastal waters. Results of extensive research have been published by the University of Victoria, the University of Western Ontario, the University of Toronto and Laval University in Quebec. The results are being used to identify behaviour that will increase survival time in the water by slowing the rate of body cooling. Even a small increase in survival time may mean the difference between being alive or dead when help arrives.

Boaters, crews working on frozen lakes and rivers, and any others exposed to the risk of accidental emersion in cold water, must be aware of the danger of hypothermia and of the factors that determine the rate the body cools, which are discussed below in a series of questions and answers.

HOW LONG CAN I SURVIVE IN COLD WATER?

Figure 13-2 shows the average predicted survival times of an average adult in water of different temperatures. The figures are based on experimental cooling of average men and women who were holding still in ocean water while wearing a standard life jacket and light clothing. The graph shows, for example, the predicted survival time is about 2 to 3 hours in water with a temperature of 10°C (50°F). Survival time is increased by extra body fat and decreased by small body size. Although women generally have slightly more body fat than men, usually they cool faster due to their smaller body size. However, for men and women of comparable size, men cool faster.

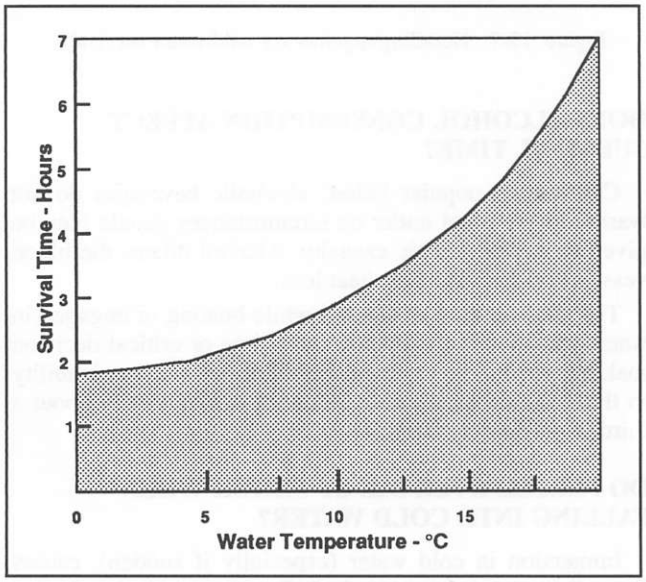


Figure 13-2. Predicted survival time for an average person immersed in cold water.

SHOULD I SWIM TO KEEP WARM?

No! Although the body produces almost three times as much heat when swimming slowly and steadily (for example, sidestroke) in cold water compared to holding still, the extra heat (and more) is lost to the cold water due to increased blood circulation to the arms, legs and skin. Experiments show that a person swimming in a life jacket cools 35 per cent faster than when holding still.

HOW FAR CAN I SWIM?

Sometimes shore may be close enough to reach despite the faster cooling rate that will result. Tests conducted on people swimming in ocean water at a temperature of 10°C (50°F) and wearing standard life jackets and light clothing showed that the average person can cover only a short distance before being overcome by hypothermia. The distance that can be covered will obviously be affected by your swimming ability, the amount of insulation provided by your clothing and water conditions. It is not easy to judge distance and the shore may appear to be closer than it actually is.

In cold water, most people can swim no more than 1/10th the distance they can easily swim in warm water. In most instances, the best advice is to stay with the boat!

WHAT IF I HAVE NO LIFE JACKET OR OTHER FLOTATION DEVICE?

You should not expose yourself to this risk, but if it happens you will be forced to use one of the following two "antidrowning" techniques: treading water or drownproofing.

TREADING WATER

This technique is recommended over the drownproofing method.

Treading water involves continuous movement of the arms and legs in various patterns in order to keep the head out of the water (Figure 13-3). Test results show the average cooling rate for persons treading water is 34 per cent faster than for persons holding still in a life jacket.

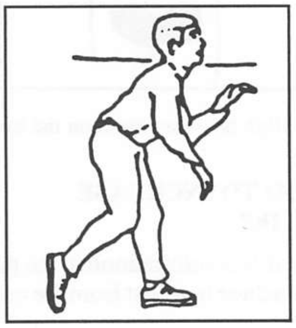


Figure 13-3. Treading water.

DROWNPROOFING

Drownproofing involves restful flotation with the lungs full of air (Figure 13-4), interrupted every 10 to 15 seconds to raise the head out of the water to breathe. Studies suggest drownproofing in cold water is the fastest way to die from hypothermia.

Experiments in 10°C (50°F) water show that the body's cooling rate is 82 per cent faster than while holding still in a life jacket. This is mainly due to putting the head (a high heat-loss area) into the water with the rest of the body.

Drownproofing is a survival technique that should only be practised in warm water.

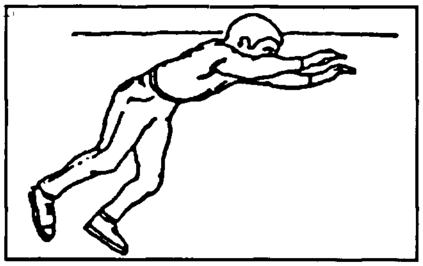


Figure 13-4. Drownproofing.

WHAT BODY AREAS ARE CRITICAL FOR HEAT LOSS?

The head and neck are the most critical heat-loss areas. Other body areas have high rates of heat loss while a subject is holding still in cold water. Infrared pictures show that the sides of the chest (where there is little muscle or fat) are the major routes for heat loss from the warm chest cavity. The groin area also loses much heat due to the large blood vessels near the surface. If an effort is made to conserve body heat, these regions deserve special attention (Figure 13-5).

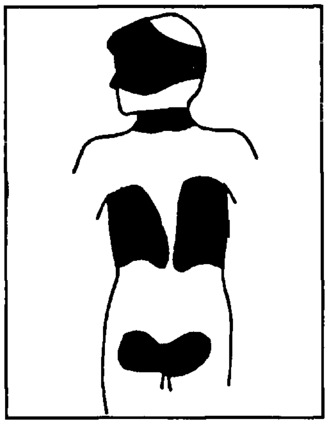


Figure 13-5. High heat-loss areas on the human body.

WHAT CAN I DO TO INCREASE SURVIVIAL TIME?

Based on the heat-loss information in the previous section, two techniques to reduce heat lost from the critical areas have been tested.

"HELP" (HEAT ESCAPE LESSENING POSITION)

This technique involves holding the inner side of the arms tight against the side of the chest covering the "hot region" described in the previous section. The thighs are pressed together and raised to close off the groin area. This body position increased predicted survival time by almost 50 per cent. It should be noted that Figure 13-6 shows a person wearing a flotation device that has all its buoyancy high on the body, close to the surface of the water. This type of device is especially suitable for HELP. This is a difficult position to maintain and it is advisable to practise it.

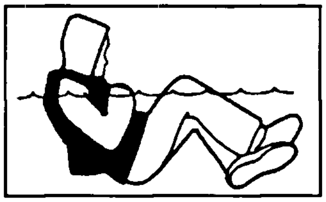


Figure 13-6. The "HELP" (Heat Escape Lessening Position) technique for cold-water survival.

HUDDLE

Survival time can be increased by survivors huddling together. Studies show that if the huddle is formed so that the sides of the chest of different persons are held close together, predicted survival time increases by 50 per cent (Figure 13-7).

As with HELP this is a difficult position to maintain and it is advisable to practise it.

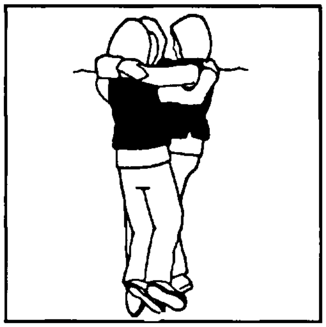


Figure 13-7. Huddling together for cold-water survival.

DOES ALCOHOL CONSUMPTION AFFECT SURVIVAL TIME?

Contrary to popular belief, alcoholic beverages do not warm a person and under no circumstances should they be given to a hypothermic casualty. Alcohol dilates the blood vessels and may increase heat loss.

The consumption of alcohol while boating or engaged in water activities is ill-advised. At a time of critical decision making, alcohol or anything that interferes with one's ability to think should be avoided. Alcohol is involved in about a third of all boating fatalities.

DO PEOPLE EVER DIE OF SHOCK WHEN FALLING INTO COLD WATER?

Immersion in cold water (especially if sudden), causes immediate major changes in body function and isolated cases of "sudden death" have been reported, but are most uncommon. The cause of this "sudden death" is not clear and many different reasons have been suggested. One is cardiac arrest resulting from the increase in heart rate and changes in blood pressure which accompany immersion in cold water. Other possible causes of death are related to hyperventilation (over breathing), which everyone experiences in response to the shock of cold water. If the victim is plunged under water or is in a rough sea, hyperventilation could lead to uncontrolled inhalation of water and result in drowning. Prolonged hyperventilation may lead to unconsciousness and subsequent drowning.

Panic magnifies all these responses and it is important to remain calm and methodical when faced with a cold-water emergency. If possible, enter the water gradually, allowing the body to adjust to the changing temperature. Consciously control your breathing as much as possible. The more clothing and insulation you are wearing, the less will be the initial shock of entry into cold water.

DOES IT HELP TO GET YOUR BODY OUT OF THE WATER?

The answer is almost invariably yes. The body surrenders its heat to the water many times more quickly than to air at the same temperature, and it is often possible to stabilize body temperature once you are out of the water. Therefore, if possible, get on top of an overturned boat or any wreckage that is available.

HOW DO YOU REWARM SOMEONE RECOVERED FROM COLD WATER?

Treatment of cold-water hypothermia victims is the same as described for victims on land. It is usually difficult to measure inner body temperature, therefore the following guidelines estimate the degree of hypothermia based on the time spent in cold water.

IMMERSION FOR LESS THAN 30 MINUTES – MILD HYPOTHERMIA

If the casualty is conscious, talking clearly and sensibly, and shivering vigorously then:

- Get them out of the water to a dry sheltered area.
- Remove wet clothing and put on layers of dry clothing; cover the head and neck (hat/scarf).
- Apply hot, wet towels and water bottles to the areas of high heat-transfer.
- If available, use electric blankets, heating pads (avoid burns) and hot drinks – **never alcohol**.
- Use hot baths or hot showers.

IMMERSION FOR 30 MINUTES OR MORE – SEVERE HYPOTHERMIA

If the casualty is getting stiff and is either unconscious or showing signs of clouded consciousness such as slurred speech, or any other apparent signs of deterioration, immediately transport to medical assistance where aggressive rewarming can be initiated.

Once shivering has stopped, it is no use wrapping the casualty in blankets if there is no source of heat. This merely keeps them cold. A way must be found to donate heat to the patient as quickly as possible. Direct body contact is most effective (*see* under Hypothermia). Handle the patient gently, avoiding jolts that might adversely affect the heart's function. **Do not rub the surface of the body**. Where possible, immediately move the patient to hospital where more sophisticated rewarming techniques and monitoring of the heart and other body functions can be carried out.

SUMMARY

In the unfortunate event of cold-water immersion, the rate of progress into hypothermia depends on a variety of factors including: water temperature, what you are wearing, your body build (particularly the percentage of body fat), weather conditions and how you behave in the water. This chapter has provided information that will help you to be prepared to increase your chances of survival, or that of someone else.

Table 13-3 summarizes the predicted survival time of the average adult in different situations (clothing worn was cotton shirt, pants, socks and running shoes) in water of 10°C (50°F).

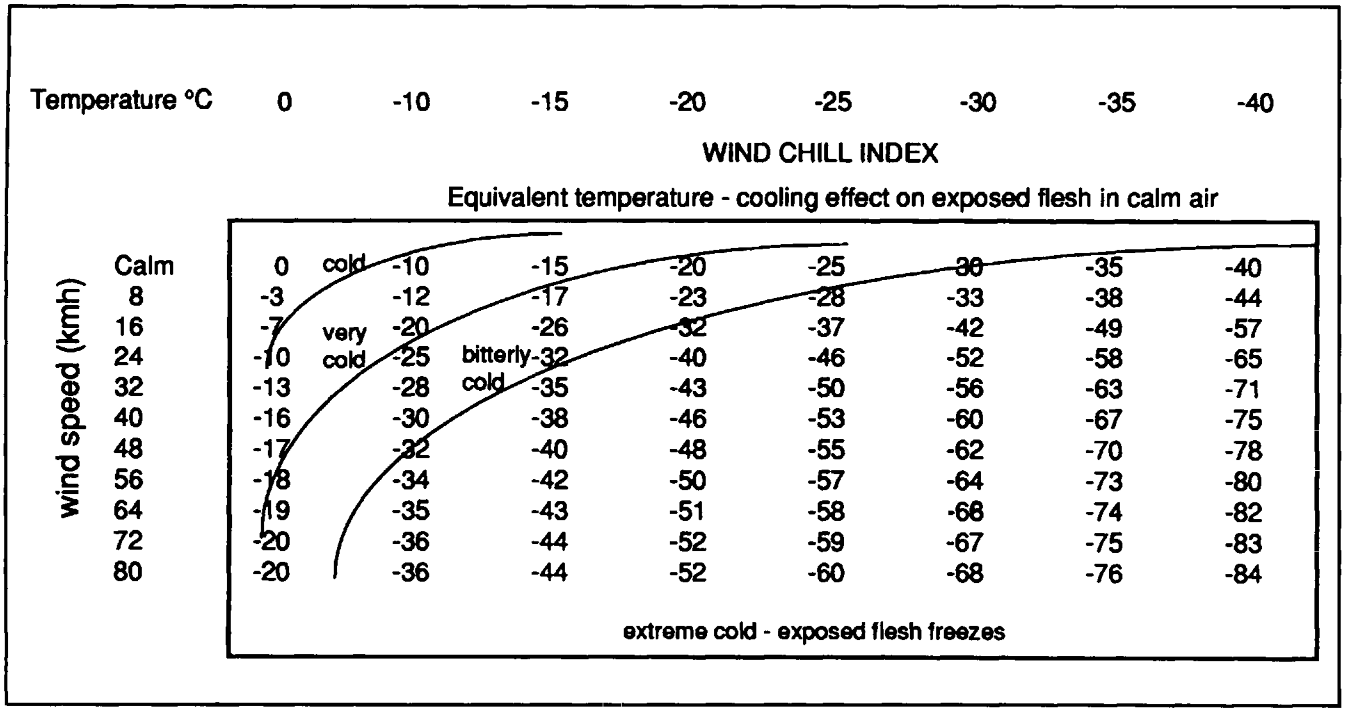
TABLE 13-3
PREDICTED SURVIVAL TIMES IN 10° WATER

Situation	Predicted Survival Time (hours) in 10°C Water
No Flotation	
Drownproofing	1.5
Treading water	2.0
With Flotation	
Swimming slowly	2.0
Holding still	2.7
HELP	4.0
Huddle	4.0
Insulated flotation jacket	7.0

WIND CHILL

Wind chill is a winter phenomenon seldom appreciated when people are working in the open in strong winds and freezing temperatures. As a result, their efficiency drops and frostbite is frequent and often accompanied by infection. Most operations have one or more thermometers to indicate temperature but very few have an anemometer or wind gauge. This instrument should be standard equipment in order that supervisors are fully aware of wind-chill hazards where crews are exposed to low temperature and wind. Workers can then be rotated frequently to jobs involving less exposure and provision made for them to get warmed from time to time while on the job. If frostbite does occur then standard first aid treatment should be given.

The wind chill table (Figure 13-8) should be posted wherever the wind and temperature recorder is mounted.



WIND CHILL INDEX

Equivalent temperature - cooling effect on exposed flesh in calm air

wind speed (kmh)	Temperature °C 0	-10	-15	-20	-25	-30	-35	-40
Calm	0	-10	-15	-20	-25	-30	-35	-40
8	-3	-12	-17	-23	-28	-33	-38	-44
16	-7	-20	-26	-32	-37	-42	-49	-57
24	-10	-25	-32	-40	-46	-52	-58	-65
32	-13	-28	-35	-43	-50	-56	-63	-71
40	-16	-30	-38	-46	-53	-60	-67	-75
48	-17	-32	-40	-48	-55	-62	-70	-78
56	-18	-34	-42	-50	-57	-64	-73	-80
64	-19	-35	-43	-51	-58	-68	-74	-82
72	-20	-36	-44	-52	-59	-67	-75	-83
80	-20	-36	-44	-52	-60	-68	-76	-84

Figure 13-8. U.S. Army Wind Chill Index modified to metric scale. Wind speeds greater than 65 km/h (40 mph) have little additional chilling effect.

APPENDIX 1

1-1 MINISTRY OF ENERGY, MINES AND PETROLEUM RESOURCES. MEDICAL EXAMINATION FOR MINE RESCUE TRAINING.

MINISTRY OF ENERGY, MINES AND PETROLEUM RESOURCES

MEDICAL EXAMINATION FOR MINE RESCUE TRAINING

(To be used in determining the physical condition of a person to wear oxygen breathing apparatus)

Name .... Age ....

Address ....

Occupation .... How long so employed ....

Employer ....

Date of last Silicosis Examination (Certificate of Fitness): ....

Medical history

asthma, bronchitis, diabetes, epilepsy, heart ailment, hernia, pneumonia, rheumatic fever spitting of blood, St. Vitus dance, tuberculosis, unsteadiness of gait, any chronic communicable disease.

Clinical examination

Pulse rate: at rest ....

after touching toes 30 times ....

Respiration rate: at rest ....

after above exercise ....

Condition of lungs and breathing passages ....

Chest expansion ....

Heart action ....

Condition of veins and arteries ....

Hearing ....

Vision ....

Nervous or composed temperament ....

Dermatitis ....

The candidate is medically fit/not fit to undergo mine rescue training.

Date .... 19 ....
Physician

Note: If a candidate has a valid Certificate of Fitness (Silicosis card) this medical examination is not required unless so requested by the Instructor.

1-2 WORKERS' COMPENSATION BOARD, FORMS 12 AND 13. CERTIFICATE OF FITNESS.

(Pneumoconiosis — Silicosis)

MINES ACT

WORKERS' COMPENSATION ACT
BRITISH COLUMBIA

CERTIFICATE OF FITNESS

Serial No. ....

Workers' Employment Record and Medical Examination to be completed by employer and examining physician and sent with a worker's chest X-ray film to the Workers' Compensation Board, Pneumoconiosis Dept., 6951 Westminster Highway, Richmond, British Columbia V7C 1C6.

(On first examination submit Form 13 also)

WORKER'S EMPLOYMENT RECORD

(To be filled in by Employer)

EMPLOYER	WORKER
Name	Name ....
Address	Address ....
Location of operation	Social Insurance No. ....
....	To be employed as ....

Date of last examination .... Where .... By whom ....

Marital status .... Country of birth ....

Number of months worked in mines or tunnels since last examination ....

Period of residence in B.C. ....

	Name of Employer	Industry (Mining, Quarrying, Stone-Cutting, etc.)	Location or Address of Operation (Mine, Factory, etc.)	Period with Dates	Employed as Miner, Carpenter, Stone-Cutter, etc.
WORKER'S EMPLOYMENT RECORD (On the **first** examination give a complete statement of all types of work done by this worker during his/her lifetime dating from his/her very first employment. On **second** or subsequent examination give the occupational record since previous examination.					

I declare all the information I have given on this form is true and correct to the best of my knowledge. This will authorize the Board and Boards of Review to obtain or view, from any source whatsoever, including records of physicians, qualified practitioners or hospitals, a copy of records pertaining to examination, treatment, history and employment of the undersigned.

...., B.C. ....
Date Signed at Applicant's Signature in Ink (do not print)

Signed for Employer ....

Official Title ....

Form 12

MEDICAL EXAMINATION
(To be filled in by Examining Physician)

Worker's Identification

Date of birth .... Weight .... Height .... ft .... ins.

Complexion .... Colour of eyes .... Colour of hair ....

		Yes	No		Yes	No
A. FAMILY HISTORY	TUBERCULOSIS	☐	☐	CANCER LUNG	☐	☐
B. PAST HISTORY (details below by number)	1. Asthma	☐	☐	11. Palpitation	☐	☐
	2. Hay fever	☐	☐	12. Irregular heart rate	☐	☐
	3. Bronchitis	☐	☐	13. Heart disease	☐	☐
	4. Pleurisy	☐	☐	14. Fainting spells	☐	☐
	5. Pneumonia	☐	☐	15. Swelling ankles	☐	☐
	6. Recurrent "colds"	☐	☐	16. Abnormal bruising	☐	☐
	7. Spitting blood	☐	☐	17. High blood pressure	☐	☐
	8. Shortness of breath	☐	☐	18. Any chest injuries	☐	☐
	9. Nose problems	☐	☐	19. Any other severe illness	☐	☐
	10. T.B. or suspected of T.B.	☐	☐			
C. PRESENT HISTORY	Any of the above? Smoking history	☐	☐	Any medications?	☐	☐

D. DETAILS (by number as above)

CLINICAL EXAMINATION: DATE: ....

1. Pulse at rest .... B/P ....
   After exercise (30 bends in 60 seconds) ....
2. Respiration at rest ....
   After exercises (30 bends in 60 seconds) ....
3. Nasal obstruction — Yes .... No ....
4. Shape of chest ....
5. Expansion in inches (arms at side) ....
6. Lungs ....
7. Heart ....
8. Chronic diseases ....
9. Pulmonary function ....
   a. FVC .... FEV1 ....
   b. Others ....
10. Fit .... Unfit ....

X-RAY EXAMINATION:

(Sputum examinations are required in cases suspected of tuberculosis)

Date of film .... 19......

Film No. ....

1. Normal chest ....
2. Tuberculosis ....
3. Pneumoconiosis ....
   ILO (1980) Classification ....
4. Heart ....
5. Other changes ....
   ....
6. Sputum examination ....

....
Signature Examining Physician

Signed this .... day of .... 19......

....
Address

Normal Chest ....

ILO (1980) Classification ....

Abnormal Findings

....

Opinion of Consultant if in disagreement with Examining Physician's diagnosis

....

....

....
Signature Medical Consultant

SUBSEQUENT CERTIFICATES

This certifies that I have examined the worker and Chest X-Ray film and have found the worker fit for work in any industry where this Certificate of Fitness is required.

DATE	PLACE	PHYSICIAN
		M.D.
		M.D.
		M.D.
		M.D.
		M.D.
		M.D.
		M.D.
		M.D.
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		M.D.
		M.D.
		M.D.
		M.D.
		M.D.

MINES ACT
WORKERS' COMPENSATON ACT
(BRITISH COLUMBIA)

CERTIFICATE OF FITNESS

Pneumoconiosis (Silicosis)

This Certificate of Fitness is to be kept in the custody of the employer and is to be returned to the worker on leaving employment, or if cancelled is to be returned to the Workers' Compensation Board, Pneumoconiosis Dept., 6951 Westminster Hwy., Richmond, B.C. V7C 1C6.

Form 13 Rev 84

Serial No. ....

WORKER'S IDENTIFICATION

Name in Full......................................

Address...

Social Insurance No. ....

Height ....cm. Date of Birth ....
Day Month Year

Colour of eyes............Colour of hair............

Complexion......................................

Distinguishing marks and characteristics................

....

....

Date...............................19......

Signature of Worker...............................

CERTIFICATE OF FITNESS

(To be filled in by W.C.B. only)

This certifies that I have examined the Form 12 and Chest X-Ray Film of

....
(full name of worker)

who is described herein and have found him/her fit for work in any industry where this Certificate of Fitness is required.

Date of Examination........................19.....

Medical Referee................................M.D.

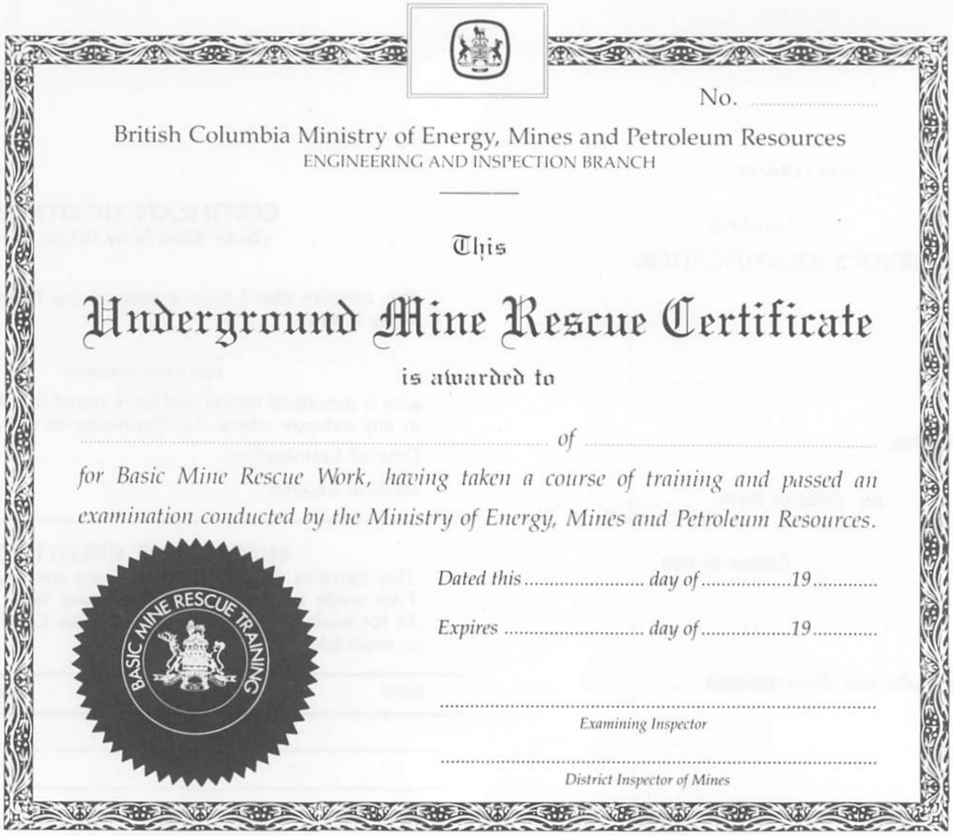
SUBSEQUENT CERTIFICATES

This certifies that I have examined and had Chest X-Ray Film made of the above named and have found him/her fit for work in any industry where this Certificate of Fitness is required.

DATE	PLACE	PHYSICIAN
		M.D
		M.D
		M.D
		M.D
		M.D
		M.D
		M.D
		M.D

N.B.—The holder of this Certificate is required to be re-examined not later than 24 months/48 months from the date of his/her last such examination for so long as he/she is engaged in any industry where this Certificate of Fitness is required. A re-examination shall be carried out at a lesser interval of time if so ordered by the Workers' Compensation Board.

1-3 UNDERGROUND AND SURFACE MINE RESCUE CERTIFICATES.



No. ....

British Columbia Ministry of Energy, Mines and Petroleum Resources
ENGINEERING AND INSPECTION BRANCH

This

Underground Mine Rescue Certificate

is awarded to

.... *of* ....

for Basic Mine Rescue Work, having taken a course of training and passed an examination conducted by the Ministry of Energy, Mines and Petroleum Resources.

Dated this .... *day of* ....19............

Expires .... *day of* ....19............

....
Examining Inspector

....
District Inspector of Mines

No. ....

British Columbia Ministry of Energy, Mines and Petroleum Resources
ENGINEERING AND INSPECTION BRANCH

This

Surface Mine Rescue Certificate

is awarded to

.... *of* ....

for Basic Mine Rescue Work, having taken a course of training and passed an examination conducted by the Ministry of Energy, Mines and Petroleum Resources.

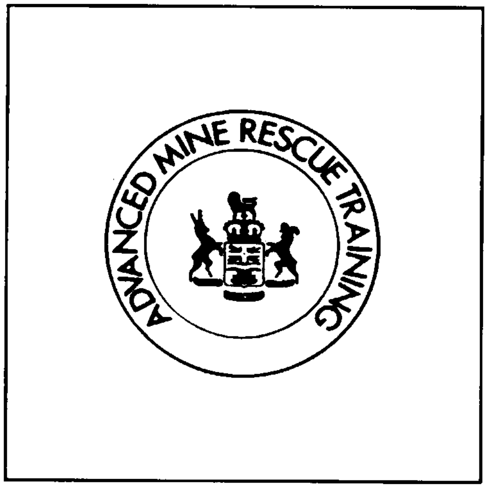
Dated this .... *day of* ....19............

Expires .... *day of* ....19............

....
Examining Inspector

....
District Inspector of Mines

1-4 "THEORY ONLY" STICKER AND ADVANCED MINE RESCUE SEAL.



APPENDIX 2

GLOSSARY OF FIREFIGHTING TERMS

AFFF	(Pronounced "A-Triple-F"). Aqueous Film Forming Foam. An extinguishing agent rated for Class A and B fires.
Ammonium phosphate	Dry-chemical base of extinguishing agent.
Backdraft	The rapid combustion or explosion of unburned carbon particles and other flammable products resulting from the sudden introduction of oxygen during the smouldering phase of a fire.
Blanketing	The action of separating oxygen from the other essentials that make a fire.
Boiling point	The temperature of a substance where the rate of evaporation exceeds the rate of condensation.
British thermal unit (Btu)	The amount of heat needed to raise the temperature of 1 pound of water 1 degree Fahrenheit.
Calorie	The amount of heat needed to raise the temperature of 1 gram of water 1 degree centigrade.
Carbon dioxide	Gas that is used to extinguish Class B and C fires by displacing the oxygen and blanketing the fire.
Centigrade (Celsius)	On the centigrade temperature scale, 0° is the melting point of ice; 100° is the boiling point of water.
Class A fire	Fire involving ordinary combustible materials (wood, paper, rubber, plastic).
Class B fire	Fire involving flammable liquids, greases and gases.
Class C fire	Fire involving energized electrical equipment.
Class D fire	Fire involving combustible metals.
CO_2	*See* Carbon dioxide.
Combustible liquid	Liquid with flash point at or above 37.8°C (100°F).
Combustion	Combustion represents the rapid combination of a fuel and an oxidizer such as oxygen or chlorine. This combination is accompanied by heat and, usually, light.
Conduction	Conduction is a transfer of heat through a medium, generally a solid. Metals are excellent conductors of heat.
Confined space	A closed space. The fire is confined to a room or building. The fire has not broken out to the atmosphere.
Convection	Convection is the transfer of heat by a medium, generally a gas or liquid. Hot gases may convect heat to the upper storeys of a burning building.
Cryogenic gas	Gas that is stored and used at temperatures below − 101°C (− 150°F).
Decomposition	The breaking apart of a molecule. The heat produced by decomposition may cause the process to go faster.
De-energize	Disconnect or turn off electrical power.
Deep-seated fire	A fire burning below the surface.
Dry compound	A type of extinguishing agent that is suitable for extinguishing Class D fires. Typically Lith-X or Met-L-X.
Electrical leakage	Flow of electrical current to the ground through a material other than that designated.
Electrical resistance	The ability of a material or substance to resist the flow of electrical current.
Endothermic reaction	A chemical reaction in which a substance absorbs heat energy.
Exothermic reaction	A chemical reaction in which a substance releases heat energy.
Expellant	Substance (air, nitrogen) used to force the extinguishing agent out of the cylinder.
Extinguishing agent	A substance that has the ability to suppress a fire.
Faceplate	A "label" attached to an extinguisher that contains information about the extinguishing agent and the operation of the extinguisher.
Fahrenheit	On the Fahrenheit temperature scale, 32° is the melting point of ice; 212° is the boiling point of water.
Fire	A rapid, self-sustaining oxidation process accompanied by the generation of heat and light of varying intensities.

Fire point	The temperature at which a liquid fuel will produce vapours sufficient to support combustion once ignited. The fire point is usually a few degrees above the flash point.
Fire spread	The travel of fire.
Flammable or explosive limits	The percentage of a substance in air that will burn once it is ignited. Most substances have an upper (too rich) and a lower (too lean) flammable limit.
Flammable liquid	Any liquid with a flash point below 37.8°C liquid (100°F) and having a vapour pressure not exceeding 275.8 kPa (40 psi) (absolute) at 37.8°C (100°F).
Flashover	The simultaneous ignition of all the contents of a fire area.
Flash point	The minimum temperature at which a liquid fuel gives off sufficient vapours to form an ignitable mixture with the air near its surface. At this temperature, the ignited vapours will flash but will not continue to burn.
Fuel load	The weight of the combustible materials found in both the structure and contents of the building.
Halon 1211	An extinguishing agent (liquefied compressed gas) that will not support combustion. Rated for Class A, B and C fires.
Hand-operated pump extinguisher	For water agents only, a pump-tank extinguisher equipped with a double action pump operated by an up-and-down or side-to-side stroke. Delivers a continuous stream of water.
Heat	The form of energy that raises temperature. Heat is measured by the amount of work it does.
Horizontal extension	The spread of fire as it travels horizontally along a hallway or from one room to another on the same level.
Hydrocarbon	A hydrocarbon is a compound composed of two elements: hydrogen and carbon. Many common fuels are hydrocarbons, such as gasoline, natural gas and propane.
Hydrostatic testing	Pressurizing the container with water to above operating pressure, to ensure that it will hold operating pressure safely.
Ignition temperature	The ignition temperature of a substance is the minimum temperature to which the material must be heated in order to initiate self-sustained combustion independent of the heating source.
Incipient fire	The first phase of a fire when room temperature has risen only slightly.
Inert gas	A gas such as carbon dioxide or nitrogen that excludes oxygen or dilutes it below the concentration necessary for combustion.
Leeward	The side of the burning building sheltered from the wind.
Liquid-to-gas ratio	The relationship between a cryogenic gas's liquid volume and the gaseous volume. When 1 litre (0.22 gallon) of cryogenic hydrogen, for example, is heated in an unconstrained vessel, it will expand to 840 litres (185 gallons) of hydrogen gas at normal pressure. The liquid-to-gas ratio is thus 1:840.
Mono-ammonium phosphate	Combined with barium sulphate to form a multipurpose dry chemical for extinguishing Class A, B and C fires.
Mushrooming	Term used to describe fire and heat gases spreading out laterally at the top of a structure.
O_2	Oxygen.
Oxidation	The chemical reaction of organic or inorganic materials with oxygen or other oxidizing agents in the formation of more stable compounds.
Oxidizing agent	A substance which, in itself not necessarily combustible, may cause or contribute to the combustion of other materials, generally by yielding oxygen.
Portable extinguisher	A device for suppressing or extinguishing fires that can be easily carried to a fire.
Potassium bicarbonate	Dry-chemical base of extinguishing agent.
Potassium chloride	*See* Potassium bicarbonate.
Pressure gauge	On stored-pressure types of extinguishers, the gauge that indicates the pressure of the charge in the cylinder.
Pyrolysis	The chemical decomposition of a substance through the action of heat.
Quenching	The suppression or extinguishment of fire by cooling.
Radiation	Radiation is the transfer of heat which is not dependent upon any medium: heat rays traveling through a vacuum from the sun to the earth, for example.
Reducing agent	Any fuel (solid, liquid or gas) that can be oxidized.

Re-ignition	The restarting of a fire.
Residue	The portion of an extinguishing agent that remains after extinguishment of a fire.
Self-expellant	An extinguishing agent that generates sufficient vapour pressure at normal operating temperature to expel itself from its container.
Service pressure	The normal operating pressure as indicated on the gauge or faceplate of the extinguisher.
Smothering	*See* Blanketing.
Sodium bicarbonate	*See* Potassium bicarbonate.
Solubility	A measure of the capacity for a substance to dissolve in a liquid, usually water.
Specific gravity	The ratio of the weight of a substance to the weight of an equal volume of water. The specific gravity of water is 1.0.
Stack effect	Also referred to as "chimney effect", this is the air or smoke movement through a building. Simply stated, cool air enters the lower levels of a building and warm air within the building rises to the upper levels.
Stored-pressure extinguisher	The extinguishing agent and expellant are stored in a single cylinder.
Sweep	To move back and forth with even strokes across an area.
Tamper-seal indicator	A thin wire or lead seal attached to the discharge device of an extinguisher after recharging. Breakage indicates usage of the extinguisher.
Thermal decomposition	The breaking down or decomposition of a substance by exposure to heat.
Underwriters' Laboratories, Inc. (UL)	An American agency that performs tests on equipment and rates that equipment against an accepted standard for commercial or public use. The equivalent Canadian agency is called Underwriters' Laboratories of Canada (ULC).
Vapour density	The relative density of a vapour or gas compared with the density of air. Air is rated as 1.0. If a gas or vapour is lighter than air, it will have a rating less than 1.0.
Ventilation	Applied to firefighting, the planned and systematic release and removal of heated air, smoke and gases from a structure, and the replacement of these products of combustion with a supply of cooled air.
Vertical extension	The spread of fire as it travels in an upward direction. This can be through the ceiling, up a stairwell, up a shaft such as used for elevators, or through the walls.
Wetting agent	An agent that is added to water to reduce the surface tension and increase its spreading and penetrating characteristics.
Windward	The side of the burning building facing the wind.

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