Saskatchewan Mines
Emergency Response Program

Saskatchewan Mine Rescue Manual

July 1, 2017

Introduction

This manual is intended as a guide for mine rescue training and response in Saskatchewan mines. It has been compiled with the input of the mine rescue instructors of Saskatchewan and is based on their experience and expertise in responding to mine emergencies. A special thanks to all the Saskatchewan Mine Rescue Instructors who contributed to this manual.
This manual is not a complete "how to" guide for all situations but should cover the basics needed for Underground Mine Rescue teams to respond safely and effectively to most situations. Every emergency is different therefore good judgment based on sound mine rescue practices must be used. This is an effort to establish and standardize those sound practices. It is expected that all Saskatchewan mines will use this manual in training of their teams and as a reference during emergency response.

Chapter Five of this manual state;
Mine rescue and recovery work involves a wide variety of tasks. Four fundamental principles exist for an effective mine rescue operation. These principles, in order of importance, are:
1. Ensure the safety of the mine rescue team.
2. Make every effort to rescue or secure the safety of trapped workers.
3. Protect mine property from further damage caused by fire, cave-in, etc.
4. Return the mine to a safe condition so operations can resume.

The first two principles must be adhered to at all times, the safety of the team and other workers are our primary concern. Protecting the mine and return to operations is secondary. Financial concerns must never be placed before safety.

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History of Mine rescue in Saskatchewan

Mine Rescue originated in Saskatchewan in 1933 with the establishment of a Mine Rescue Station at Flin Flon, Manitoba by Hudson Bay Mining and Smelting Company (HBMS). Although this was on the Manitoba side of the border it serviced the Saskatchewan mining industry which was located primarily in the Flin Flon area at that time.

In the early 1950s, several uranium mines in the Beaverlodge area of northern Saskatchewan came into operation. Jack Chrisp, of Hudson Bay Mining and Smelting, flying in from Flin Flon, Manitoba, conducted the first training in our province. Workers were instructed in the use of the one hour Chemox and the two hour McCaa self-contained breathing apparatus as well as the Type “N” or Universal gas masks.

Jack Chrisp

In 1957, the provincial government established and operated a mine rescue station in Uranium City to service some of the smaller mines in the area such as Rix Athabasca, Cayzor and Lorado and provide back up for the larger mines such as Eldorado and Gunnar Mines which had their own station. Herb Aitchison, the resident Mine Inspector at the time, was placed in charge. Equipment and training were provided through the station. Manpower was provided by the mining companies.

Beaverlodge Headframe, Uranium City

Herb Aitchison was placed in charge of training mine rescue workers and was assisted by instructors at each operation. These instructors were appointed by the mining company and certified as trainers by the government. By the mid-1970s, the task of training mine rescue personnel was put entirely in the hands of the mining companies, under the direction of the Provincial Mine Rescue Coordinator.

A van unit was used for the purpose of transporting equipment from mine to mine until the mines became fully equipped with apparatus of their own.

With the closing of some of the uranium mines in the northern part of the province and the development of potash mines in the south in the early 1960s the government mine rescue station was moved to Regina. The Mine Rescue sub-station at Eldorado in the Uranium City area was maintained. Eventually, mine rescue sub-stations were also established at the Anglo Rouyn mine near La Ronge and at eight underground potash mines in the south.

In the 1970s, the task of training mine rescue personnel was put entirely in the hands of the mining companies, under the direction of the Provincial Mine Rescue Coordinator. "Certificates of Competency as a Mine Rescue Person" were issued by the Government of Saskatchewan following the completion of the company training as well as a written provincial exam. A practical component has now been added to the exam.

In 1977, the government operated Mine Rescue Station was moved to Saskatoon, to be in a more central location for the potash mines. In the early 1990s, this station was closed and the equipment was sold.

In 1974, with the retirement of Herb Aitchison, John Woroniuk took the role of the Government Inspector and provincial Mine Rescue Coordinator. Following John's retirement in 1992, the position was not filled again until 1997. The provincial Mine Rescue Coordinator has the responsibility of coordinating the mine rescue program for the Government of Saskatchewan.

Records show that the first mine rescue certificate was issued in Saskatchewan in April, 1956. From April 1956 to 1967, there were 90 certificates issued. To date there have been approximately 2850 workers trained and certified for mine rescue work and 176 certified as mine rescue instructors in Saskatchewan.

Over the past sixty years, our mining methods have changed and with these changes, mine rescue methods have also changed. Major improvements in breathing apparatuses have improved the safety and duration of rescue missions. Initially, the one hour Chemox then the two hour McCaa were standard. In 1967, most of the two hour self-contained breathing apparatuses were replaced with the four hour Draeger BG-174 units.

In 1991, newer types of primary self-contained breathing apparatus were introduced. These are positive pressure units and cool the breathing air thus improving safety and comfort. At present, all Saskatchewan mines use either the Biomarine Bio-Pak 240 or the Drager BG4 as breathing apparatus for mine rescue emergencies. As of 2016, there were 80 Drager and 168 Biomarine four hour breathing apparatuses in use in Saskatchewan mines.

Traditionally, most mine rescue missions involved 5 man teams carrying all their supplies on a stretcher. Due to the size of our mines this is no longer practical and most mines now have dedicated mine rescue vehicles.

Saskatchewan has always endeavored to standardize mine rescue training to conform to the rest of Canada. This paid off in 1991 when 16 mine rescue workers from three Saskatchewan mines helped to control a fire at Smokey River Coal at Grande Cache, Alberta. Saskatchewan has been fortunate to not have had a major disaster where large numbers of rescue people from the other provinces were required.

The benefit of standardized training over the years has also been demonstrated by the ability of all mines within the province to respond and aid other mines when the nature or magnitude of the emergency requires it.

The high standards to which the Saskatchewan Mine Rescue workers train has resulted in a very successful program. To date there has never been a Mine Rescue worker lost in the line of duty in the province. In every case were Mine Rescue teams have responded to a mine fire in Saskatchewan the teams have managed to successfully control the emergency and safely bring all workers to surface. This is a part of our industry's history which all mine rescue persons should be extremely proud of.

Chapter One - Mine Gases

Introduction

It is generally assumed when referring to gases in the mining environment that the interest is in toxic gases, however, the concentration of nontoxic gases, such as oxygen, can be of importance.
Gases in the mine environment come from different sources. The major concern about most gases is their toxicity to workers. If the concentration of and exposure time to a gas are sufficient, illness or death may result.

Workplace exposures are measured as threshold limit values (TLV). They are further divided into three levels; time weighted average, short term exposure limits and immediately dangerous to life and health. The Occupational Health and Safety Division of the Ministry of Labour Relations and Workplace Safety (LRWS) is responsible for setting allowable levels of exposure to gases in the workplace. The regulation of the workplace environment is a well-accepted process and serves to protect mine employees in their daily work.

Threshold limit value – time weighted average (TWA) can be defined as an allowable concentration of a gas that a worker can be exposed to for an eight hour day, averaged over a 40 hour week, over a working lifetime that will cause no adverse effects.

Threshold limit value – Short term exposure level (STEL) can be defined as a concentration of a gas which should not be exceeded for a period of more than 15 minutes, and no more than four times in a day. There should be at least 60 minutes between the successive exposures at or above the STEL.

Threshold limit value - immediately dangerous to life and health (IDLH) can be defined as a concentration of a gas that poses an immediate threat of severe exposure to contaminants. If a concentration is above the IDLH, only positive pressure breathing apparatus should be used to enter the atmosphere.

During an emergency, when a toxic gas or gases are released into the workplace, the concentration of the toxins can exceed normal workplace standards. Being knowledgeable of the contamination limits of gasses will assist in making decisions to take workers from refuge following a mine fire situation. Consideration can be given to the exposure time to be removed from the mine versus the potential health effects at known concentrations. For example, expecting all air to be completely void of carbon monoxide is impractical knowing that in Saskatchewan mines it is common to be around 7 ppm due to mine air heaters alone.

These decisions will be made by the incident command team at the mine during the emergency.

General properties of gases

The term gas refers to the physical state of a substance at room temperature and normal atmospheric pressure that, when unconfined, expands to fill the space it occupies. At reduced temperatures or high pressures, a gaseous substance can exist in a different physical state. Examples include the liquid

Propane gas (LPG) and the solid dry ice that, at room temperature would be gaseous propane and carbon dioxide.

Traditionally, mine rescue teaching about gas properties focused on the density of pure gases. However, gases in a workplace in emergency situations are often not pure, but are mixed with air and other gases. Pure gases seldom exist in the workplace, and when they do, it is likely that the gas was released from a pressurized vessel discharging uncontrollably. Even a leak of pure, pressurized gas will not perform like a pure gas as the distance from the leaking vessel and turbulence increases. Eventually, the leaking gas will mix with the surrounding air as it moves away from the source of the leak.

Stratification of gases does occur where the gas mixture has a significant difference in density from the surrounding air. A good example is the gases produced during a fire. Because of the heat of combustion, the gases that are released from burning material are hot and less dense than air at normal conditions. As a result, combustion gases generally rise. This mass of hot gas, or package, has a diffuse boundary and is lighter than the surrounding air. The fact that heated gas responds as an unconfined mass is readily visible from chimney smoke in cooler weather. The smoke has buoyancy and rises until the package of gas has mixed and cooled to the same point as the surrounding air. Because of turbulence and diffusion, the package of gas is diluted to the point where it differs little from air alone.

There are other physical properties of gases, such as taste, colour, and odour that may or may not be helpful as warning properties. For example, the property of colour is often best observed with pure gases and workers may or may not be able to smell a gas (depending on its concentration). Therefore, these properties may serve little purpose in understanding the toxic nature of a gas when it has been mixed with mine air.

Effects of dilution

Air is primarily composed of oxygen and nitrogen. If another gas is evenly mixed with air, as happens given a sufficient amount of time, the concentration of oxygen and nitrogen will be proportionally reduced.

For example, assume that a gas is introduced into a confined space containing air and that there is no chemical reaction consuming the oxygen. The resulting effect is simply dilution. If the introduced gas is measured at 10 per cent, the oxygen and nitrogen in the air will be diluted by 10 per cent.

The reduction in oxygen and nitrogen concentrations can be determined by the following formulas. Note: For simplicity, the actual concentrations of oxygen and nitrogen have been rounded off to 21 per cent and 78 per cent respectively.

The actual Oxygen concentration has been diluted by 10 per cent and so is 0.9 X 21 per cent = 18.9 per cent. The actual Nitrogen concentration has also been diluted by 10 per cent and so is 0.9 X 78 per cent = 70.2 per cent. Adding up the concentrations of the introduced gas (10 per cent), oxygen (18.9 per cent) and nitrogen (70.2 per cent) equals 99.1 per cent. If you apply the above concept to the original air which contained 1 per cent other gases, the missing 0.9 per cent is accounted for.

In the above example, if the oxygen had been diluted by 20 per cent, the actual oxygen concentration would be X 21 per cent = 16.8 per cent. If the nitrogen had been diluted by 20 per cent, the actual nitrogen concentration would be 0.8 X 78 per cent = 62.4 per cent.
Such calculations are not intended to be a substitute for air monitoring. They serve only to explain the principle of dilution and the effect of dilution on the concentration of the individual components of air.

Gas accumulation and stratification

Gases can collect in pockets separate from the rest of the mine air. This is especially true where mines lack adequate ventilation. Hot gases from a fire will rise to the back and remain there until the smoke has time to cool and mix with the air. Therefore, expect the smoke near a fire to be denser at the back. The smoke will be more uniformly distributed in a drift once it moves away from the fire and is mixed with the mine air by ventilation flows and turbulence.

A second example of gas stratification is the distribution of methane in a coal mine. Pure methane has a relative density about one-half that of air and can be produced in massive quantities in an underground coal mine. Such large amounts of methane will physically displace the other mine air. Because of its low density, there may be pockets of methane that will tend to accumulate near the back.

Small differences between the density of a gas and of air will not cause stratification. For example, oxygen is 10 per cent more dense than air. However, the oxygen will not be more concentrated near the floor in a room or a stope. It remains thoroughly mixed with the rest of the mine air.

Gases derived from combustion processes

The combustion of organic material and hydrocarbon fuel results in the formation of carbon monoxide and carbon dioxide. Generally carbon dioxide is produced in larger quantities while carbon monoxide is produced in smaller amounts where combustion is not 100 per cent efficient.

Nitrogen dioxide and other oxides of nitrogen, sulphur dioxide, hydrogen cyanide and phosgene may be produced by combustion. Burning various plastic or synthetic materials will result in some production of these gases. Base metal mines such as those that produce copper or zinc derive the metals from sulfide ores. In cases where the ore caught fire after a production blast, a large quantity of sulphur dioxide was produced.

Industrial gases

An industrial gas is produced for a commercial application. Some of the most common industrial gases found in the mining industry are natural gas or methane, propane and acetylene. Some are burned to provide thermal comfort or to do work involving high heat such as cutting metals or brazing. These industrial gases are derived from fossil fuels and are composed of carbon and hydrogen. When burned they produce carbon dioxide, water vapour and carbon monoxide. The most well-known danger from the combustion of these gases is carbon monoxide poisoning, even though the carbon monoxide is generally produced in small concentrations. Because of its affinity for red blood cells even at a low concentration of several hundred ppm, carbon monoxide is a dangerous gas.

Industrial gases released into the workplace pose additional concerns. When released into an enclosed area, the air concentration may be sufficiently diluted resulting in asphyxiation to anyone in the space.

An explosive hazard will be produced if the concentration of the gas approaches its Lower Explosive Limit (LEL). For example, the effects of low oxygen content are discernable at 17 per cent (not asphyxia), or approximately 4 per cent lower than the normal concentration in air. If air is diluted by methane to an oxygen concentration of 17 per cent, the actual concentration of methane is approximately 20 per cent. Methane at this concentration is theoretically above the upper explosive limit. However, there will be areas where methane is explosive because of its uneven distribution in the air. For other combustible gases, try calculating the concentrations of a mixture with air and determine if the result is an explosive atmosphere.

An industrial gas released quickly and in sufficient volume from a pressure vessel will produce a cold mass of gas that may be stratified or distinctly layered near the point of its release. Whether the release occurs outdoors or indoors does not detract from the danger of a moving plume or cloud of concentrated combustible gas. The boundary of the gas plume has a concentration gradient that varies from pure air to an increasingly richer mixture in air. The plume or body of gas constantly expands until it makes contact with an ignition source. At some point the gas concentration in the plume will be at or above its lower explosive limit.

Gases used in industrial processes

Air is approximately 78 per cent nitrogen. Nitrogen does not contribute materially to the body function or to the combustion process. Because of this, nitrogen is often used to inert vessels that cannot be exposed to oxygen during maintenance. In the absence of oxygen, nitrogen becomes a lethal asphyxiant.

Conversely, an environment that is oxygen enriched will support rapid burning which can be extremely dangerous.

Ammonia gas is caustic and breathing its vapours in sufficient quantities can damage lung tissue and impair breathing. When released from a pressurized vessel the extreme cooling effect of the expanding gas will cause skin to freeze.

Gases from explosives

The detonation of commercial explosives creates the same gases found from burning fuel. The presence of carbon and nitrogen in commercial explosives makes it likely that carbon monoxide, carbon dioxide and some nitrogen oxides will be produced from a blast, or released from the blasted material while reclaiming or removing operations are taking place.

Natural occurrences of gases

Hydrogen sulfide:

Hydrogen sulfide in the mining environment is derived from water. In the Saskatchewan potash mining industry, hydrogen sulfide is derived from water entering mined areas from either the Dawson Bay or the Winnipegosis Formation. The dissolved hydrogen sulfide in the water originates from bacterial decomposition of soluble sulfate in the water. Once the water enters the mine, hydrogen sulfide is released into the mine air in the absence of hydrostatic pressure. The solubility of hydrogen sulfide in water is relatively low at mine atmospheric pressures.

When the water inflow area has restricted ventilation, hydrogen sulfide will build up in the area of the inflow. Levels of 100 ppm are not unheard of in unventilated caverns with water inflows. Although 100 ppm is not an immediately lethal concentration, extended and unprotected exposure beyond one-half hour can lead to unconsciousness and may ultimately lead to death.

Decomposition of organic material such as sewage can lead to the formation of hydrogen sulfide if sulphur compounds are in the decaying material. Water wells with intakes at the bottom of the reservoir have brought hydrogen sulfide into the pump house with deadly results to workers.

Carbon dioxide:

Carbon dioxide is the natural metabolite produced in the human body and exhaled in the respiratory process. In sufficient concentration, naturally exhaled carbon dioxide is hazardous. The exhalation of carbon dioxide by workers in refuge stations can create hazards. A dead air space is commonly employed for refuge underground in the potash industry. Hard rock mines commonly use much smaller refuge stations supplied with compressed air. Refer to the section entitled “Gas in Enclosed Areas” for additional information.

Methane or natural gas:

Methane is a product of the decomposition of organic matter. Methane is also produced when sewage or other organic matter is subject to stagnant conditions and bacterial action. Coal beds may also contain methane and subsequently release the gas when the bed is exposed during mining. Methane is very dangerous in underground coal mines where inadequate ventilation can result in levels building up to explosive concentrations.

Oxygen deficiency/depletion

The biological effect of oxygen depletion is similar to asphyxiation. However, the physical processes leading to oxygen depletion are different. Oxygen depletion requires two factors to produce a hazardous condition. A chemical reaction called oxidation is necessary to consume oxygen from the surrounding air and there must be limited incoming fresh air to replace the oxygen that has been consumed. Oxygen deficiency can be produced by displacement from another gas.

Some base metal mines, such as those found in northern Saskatchewan and Manitoba, produce copper and zinc sulfide minerals. These minerals contain iron sulfides such as pyrrhotite which have high oxidation rates. Fatalities have resulted when workers entering a stope with mill tailings that have undergone oxidation. Oxygen depletion from coal storage bins has also been reported. Such depletion likely originated from iron sulfides found in the coal.

Measuring gas concentrations

The measurement of gases has always been an important component of mine rescue. One of the common questions asked of instructors today is where to measure for a toxic or explosive gas. Typically, the instructor will refer to the specific gravity of a pure gas, and state that sampling should be done high or low because gases find elevations relative to their specific gravity. In general this is not an accurate evaluation. As discussed, the behaviour of gases is much more complex.

In most cases where a toxic gas is encountered, it is already mixed with the mine air. Even a very toxic mixture of H2S at 1000 ppm is virtually the same density as air alone. There is no density stratification of the H_2S because, at 1000 ppm, the mixture is still 99.9 per cent air. However, there may be a concentration gradient near the source depending on the extent of mixing from turbulence and diffusion.

Gases respond to thermal differences. For example, hot combustion gas is largely composed of CO_2 and some CO, and represents a package of gas that is heavier than air. However, because these gases are hot, they tend to be buoyant relative to the surrounding cooler air. The smoke containing these gases will rise, dilute, mix, and cool, becoming indistinguishable from air.

Conversely, cold gas formed during release from a compressed cylinder will be dense and tend to gravitate close to the ground surface or in a pit. Such a cold air mass could flow into a nearby sump and remain there for some time in the absence of good mixing. Cold gas will normally mix with mine air due to turbulence, dilution and warming, and will eventually be uniformly distributed throughout the mine atmosphere.

The best place to take gas samples is where the gas could be harmful. This would be in the breathing zone and in any area where people may be present. Following this test a rescue team should test in the area they would expect the gas to be if stratification had occurred when they are testing for a specific gas.

Samples might also be taken along the potential mixing front of a gas. However, a mine rescue team taking the samples should remain alert to the possibility of gas stratification as discussed in the previous section.

Gas Monitoring Equipment:

Historically, the flame safety lamp has been used in mine rescue operations for over one hundred years for gas testing. With the introduction of electronic gas detecting instruments, the use of the flame safety lamp has been discontinued. Currently the equipment used to measure the concentration of gases comes in two types: the colorimetric or length-of-stain tube system, and the electronic gas detector.

Important: Refer to the manufacturer's instructions for use of gas detecting equipment.

Colorimetric (length-of-stain) tube system:
This method of gas detection is comprised of a glass tube and pump. Although there are several different designs for the stain tube system, they all work on the same principle. In each case, the manufacturer has developed a tube that changes colour along the length of the tube

in proportion to the concentration of the gas in the air. A known quantity of air, usually in multiples of 100 ml, is pulled through the tube after the two glass ends have been broken and the tube is inserted properly into the pump. Drawing 100 ml of air with the pump is termed a stroke. Most pumps are designed to draw 100 ml of air per stroke but some pumps are capable of pulling a half stroke or 50 ml.

Another more modern version of the colorimetric tube tester uses a pump to draw the sample through the tube, and can hold ten tubes on one chip. This type of tester also interprets the results for the user and displays the results on a direct readout screen on the instrument.

The colorimetric tube detection system has several advantages:

- The system is relatively accurate (usually + or – 25 per cent) if the user follows the manufacturer's recommendations and precautions. Numerous gases can be monitored relatively inexpensively, but a large inventory of tubes is required to provide the flexibility to monitor several gases at different concentrations;
- The system does not require calibration. One disadvantage of the detector tube is its limited shelf life, which requires paying close attention to the expiry date; and
- Another disadvantage is that several strokes and minutes are required to obtain a reading.

The basic rules to follow when measuring gas levels with a detector tube system include:

- Become familiar with and use the fact sheet provided with each box of tubes. It contains important information on the effects of humidity and interference, to name just a few points;
- Conduct a leak test to check the state of the bellows or piston, and tube seats;
- Break off ends of gas tubes;
- Ensure gas tubes are firmly seated in the pump and placed with the arrow pointing towards the pump;
- Determine the appropriate number of strokes for the tube, especially if the tube is a multi-stroke tube and has two scales;
- Check that sufficient time has elapsed for the sample;
- Allow bellows to fully deploy and, with piston pumps, be sure that the vacuum has returned to atmospheric pressure;
- Check the detector tube fact sheet for possible interference or cross-sensitivity from other gases. Cross-sensitivity can have positive or negative results; and
- Read the tube where there is a colour change; take the reading as soon as the sample is taken and before bleeding of the colour interface has occurred.

Electronic gas detectors:

Electronic gas detectors have come a long way in reliability, cost and gas detection capability. However, these devices remain an expensive alternative to length-of-stain systems and the costs are higher with each detector the unit is fitted with. Electronic gas detectors are generally fitted with an audio alarm that can be set to sound at certain concentrations. Changing contamination levels are assessed almost instantaneously.

Electronic gas detectors have limitations. Typically, these detectors function at the lower ranges of gas concentrations with levels mostly associated with normal industrial hygiene surveys and concerns. Of course, there are exceptions. Oxygen and combustibles in the acutely hazardous range can be adequately assessed with an electronic gas detector. Regular monthly calibration is necessary, but for critical circumstances, it is recommended that the unit be calibrated prior to its use. Testing or bumping with a test gas may be used to test the instrument's response. Although gas detection instruments are shielded from radio frequencies by metal or metal impregnated cases, the instrument may be affected when a radio is keyed with the instrument close by.

In spite of these limitations, an electronic gas detector is a very valuable piece of equipment for measuring the preliminary concentration of a gas in an emergency and for giving an "all clear" to workers after an emergency.

Gas in enclosed areas

During an emergency, workers may have to seal themselves into a heading to create a cocoon of breathable air around them, or they may seek refuge in a mine refuge station. When a seal is used, there is no replenishment of the oxygen consumed nor is there dilution of the expired carbon dioxide.

The same situation occurs in potash mines where the volume of the dead air space in a refuge centre provides breathable air for workers. For a short period of time and a small number of workers, elevated carbon dioxide is not a major concern.

It has been generally assumed that the provision of oxygen or air from pressurized cylinders is sufficient to maintain an adequate supply of breathable air. Given sufficient time and number of workers, the expiration of carbon dioxide can create a toxic environment in the occupied air space. If there are no provisions in place to eliminate the dangerous carbon dioxide, adding extra oxygen cylinders will do very little to extend the safe occupancy time for the workers that are in the refuge station.

There are commercial solutions for carbon dioxide removal such as large, refillable, powered scrubber units such as a Rana or simple to use Extend-Air curtains that are deployed and discarded following use.

Although what all the existing provincial regulations give for guidance on time and capacity of refuge stations is "36 hours of breathable air for the number of workers expected to use the refuge station," some basic design rules-of-thumb have been used. A maximum design concentration of 3 per cent carbon dioxide with a minimum of 16.25 per cent oxygen at 8-24 hours is recommended by MASHA* in their "Guidelines for Mine Rescue Refuge Stations." MASHA summarized the various models for dead air space design. All models produce similar results of 5.7 to 6.2 m^3 of dead air space per person to limit the CO_2 concentration to 3 per cent after eight hours. To maintain the same upper limit of 3 per cent CO_2 for a 24 hour period would require three times the dead air space volume (~18 m^3 per person).

For refuge stations equipped with compressed air, such as those commonly found in hard rock operations, design flows should maintain an adequate oxygen supply. It is critical that sufficient air be provided to dilute the CO_2 exhaled in the worker's breath. MASHA says that flow rates of 50 to 100 scfm (standard cubic feet per minute) per person are required to keep CO_2 levels to less than 5000 ppm. The use of standard sized (300 ft^3) cylinders is impractical for providing extended protection because of the large volume of compressed air required for dilution.

As a result of these required airflows, there needs to be an outlet designed in the refuge station that will be small enough to make sure a positive pressure is maintained while not allowing the pressure to build up to a point that could damage a refuge station seal.

Mine rescue personnel should be acquainted with basic design considerations for the capacity of a refuge station. Refuge stations should be designed to handle the required number of workers who could be sent to them.

Mine clearance

Following a toxic gas release, one of the main tasks of the mine rescue team is to determine if it is safe for other workers to return to the mine.

If the gas concentration is below a recognized workplace contamination limit established for extended exposure, it should be safe to return to normal operations. Remember that the basic assumption of the threshold limit concept is that below the TLV, a person should not experience ill health from exposure at that concentration for a working lifetime. It is important to have calibrated electronic gas detection equipment or low concentration gas tubes available for evaluating the air.

In the event a worker is in a medical emergency, he or she may need to be removed from safe refuge even if the air outside is not below the established TLVs. Before this type of decision is made, a risk assessment must be completed to ensure all worker safety precautions are taken.

Summary

The most serious emergencies underground originate from fire. Surface emergencies may involve process gases as well.

Of major concern from a fire are the gases carbon monoxide and carbon dioxide that are derived from the process of combustion. Although other gases may form when synthetic materials are burned, these may be of lesser importance compared to the effects arising out of exposure to carbon monoxide and carbon dioxide, and the depletion of oxygen.

Gas properties and characteristics

This section provides detailed information on gases that may exist in a mine and its surface operations due to an unusual condition or emergency. However, other gases not discussed in this chapter may exist in small quantities.

The gases are listed alphabetically however seven are separated out for detailed explanation in this manual. These are the gases that are most commonly encountered in Saskatchewan mines and can have an adverse effect on workers. They are also referred to as our core gases for mine rescue study and examination purposes.

- air
- carbon dioxide
- carbon monoxide
- hydrogen sulfide
- nitrogen dioxide
- oxygen
- radon

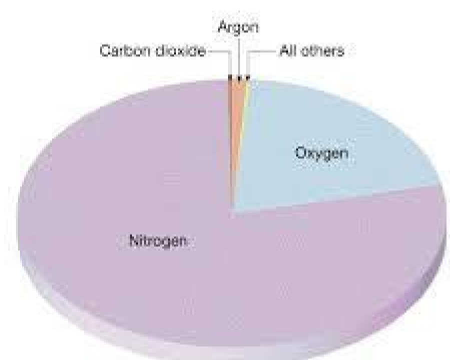
Except for the section on air, most gas descriptions here are broken down into six subsections. The first subsection presents known origins of the gas, with special emphasis on occurrences in Saskatchewan and neighbouring provinces, the health effects for acute exposure through inhalation, ingestion or absorption. Acute exposure refers to the severe and often dangerous effects from exposure to high concentrations of a gas for a short period of time.

The second subsection identifies the Saskatchewan workplace contamination limit. This value can be used to establish clearance after an emergency. Workplace contamination limits are based on the concept of long-term exposure that should not produce any health effects. Workplace contamination limits are shown in Table 1-2.

The remaining subsections include physical properties, methods of detection, and treatment of workers who have been acutely exposed. Some properties of the gases discussed in this section are summarized in Table 1-3.

Air

Normal air is colorless, tasteless and odorless however because it is composed of all and any gas present it may have the properties of those gases. It supplies the oxygen necessary for life. Pure, dry air at sea level is 78.09 per cent nitrogen, 20.94 per cent oxygen, 0.94 per cent argon, 0.03 per cent carbon dioxide, and contains trace amounts of other gases.



Carbon dioxide (CO_2)

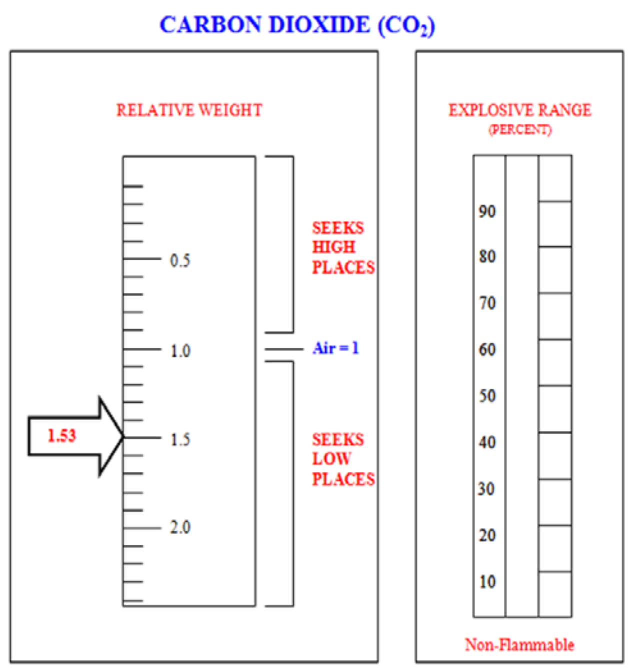
Origin: Carbon dioxide is a normal component of air (~0.03 per cent). There are no toxic effects at normal background. Although internal combustion engines produce carbon dioxide, workplace concentrations are generally controlled through ventilation.

Elevated concentrations of carbon dioxide are produced from combustion and blasting operations. However, combustion is not a chemically clean process and is accompanied by carbon monoxide in sufficient quantity to be toxic. The breathing process could produce dangerous levels of carbon dioxide given sufficient time and a lack of ventilation. Biological oxidation such as rotting will elevate the concentration of carbon dioxide in a confined area while lowering the oxygen concentration to potentially dangerous levels.

Health effects:
In spite of being a human metabolite, carbon dioxide causes physiological responses at elevated concentrations. Elevated concentrations can produce narcotic effects, stimulate respiration, and result in asphyxiation depending on the concentration and exposure time.
Health effects of exposure to carbon dioxide include:

- 3,000 – 5,000 ppm: Low concentrations cause increased respirations and headache;
- 5,000 ppm: CO_2 respiration increases by 5 per cent;
- 10,000 ppm: Symptoms may begin to occur, such as feeling hot and clammy, lack of attention to detail, fatigue, anxiety, loss of energy, weakness in the knees commonly known as "jelly legs.";
- 20,000 ppm: Respiration increases by 50 per cent, headache after several hours of exposure; and
- 50,000 - 100.000 ppm: Violent panting and fatigue to the point of exhaustion merely from respiration; severe headache; prolonged exposure at 5 per cent could result in irreversible effects.

Source: Industrial Scientific Gas detection made easy 2014



Properties: Carbon dioxide is colorless and odorless. High concentrations may produce an acid taste. Carbon dioxide does not burn.

Contamination Limits: The eight hour average limit for carbon dioxide is 5,000 ppm, short term exposure limit is 30,000 ppm.

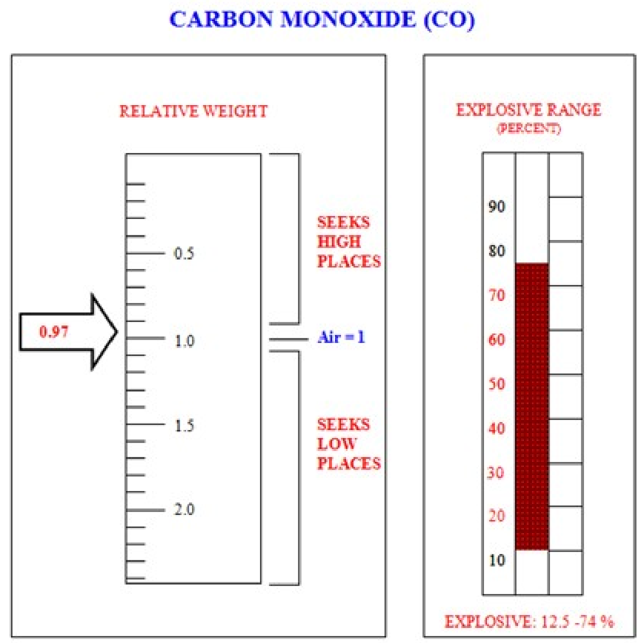
Detection Methods: Electronic detection devices and direct reading colorimetric tubes are available to evaluate carbon dioxide. Electronic detectors are more suitable for concentrations below 5,000 ppm.

Treatment of Affected Persons: Remove victim to fresh air. Give oxygen and artificial respiration if breathing has stopped.

Carbon monoxide (CO)

Carbon monoxide is highly toxic. Inhaled carbon monoxide readily binds to blood hemoglobin reducing the blood's oxygen carrying capacity. As with other toxic gases, the level and duration of exposure determine the severity of the effects.

Origin: Carbon monoxide is a product of incomplete combustion of carbon based materials. The burning or detonation of explosives also produces carbon monoxide, and it is emitted from the exhaust of internal combustion engines.



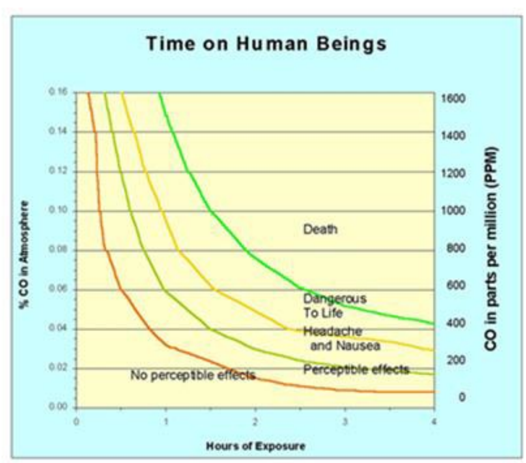
Health effects of exposure to carbon monoxide include:

- 200 ppm: possible mild frontal headache in 2 to 3 hours;
- 400 ppm: frontal headache and nausea after 1 to 2 hours; Occipital after 2 ½ to 3 ½ hours;
- 800 ppm: Headache, dizziness, and nausea in 45 minutes; collapse and possible death in two hours;
- 1,600 ppm: headache, dizziness and nausea in 20 minutes; collapse and death in one hour;
- 3,200 ppm: Headache and dizziness in 5 to 10 minutes; unconsciousness and danger of death in about 30 minutes;
- 6,400 ppm: headache and dizziness in 1 to 2 minutes; unconsciousness and danger of death in 10 to 15 minutes; and
- 12,800 ppm: Immediate effects – unconsciousness; danger of death in 1 to 3 minutes.

Source: Industrial Scientific Gas detection made easy 2014.

Properties: Carbon monoxide is flammable, colourless, tasteless and odourless. It has an explosive range of 12.5 to 74 per cent. Such concentrations are unlikely to result from a mine fire unless the fire is confined and is oxygen starved. High concentrations of carbon monoxide may be partially responsible for the event known as backdraft.

Contamination limits: The eight hour average limit for carbon monoxide is 25 ppm, short term exposure limit is 190 ppm.



Detection methods: Electronic gas detectors and direct reading colorimetric tubes are available for carbon monoxide. Electronic gas detectors are better for the lower concentrations experienced in the normal working environment.

Treatment of affected persons: Take victim to fresh air and, if possible, give oxygen immediately to lessen the severity of the carbon monoxide poisoning. If artificial respiration is necessary, oxygen should be given as soon as possible. Cardiopulmonary resuscitation (CPR) may also be required. The victim should be kept at rest and provided with medical attention as soon as practicable.

Hydrogen sulfide (H_2S)

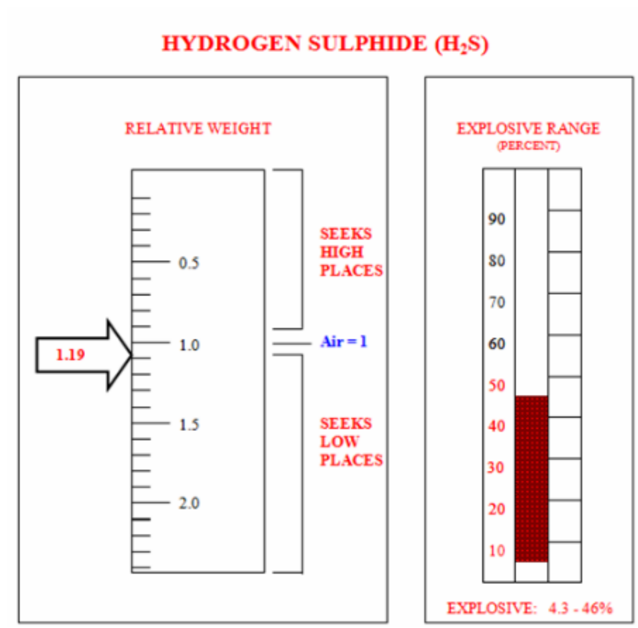
Hydrogen sulfide is highly toxic because it interferes with cellular metabolism. It blocks the use of oxygen by your body's cells (cytotoxic anoxia). Tissues that require a lot of oxygen, such as your nervous system and heart, are particularly affected.

Origin: Hydrogen sulfide is produced when sulfur compounds are chemically reduced or decompose. It is found in some oil and gas fields and in some gypsum mines. It may also be released from methane feeders in mines with methane. Hydrogen sulfide is often created when acid mine water corrodes metallic sulfides. It can also be released from water that contains the gas or sulfides in solution. Heating sulfides in the presence of moisture (as in mine fires) may produce hydrogen sulfide gas. Blasting in sulfide ores can also create and release hydrogen sulfide.

Health effects from exposure to hydrogen sulfide include:

- 10 ppm: Beginning eye irritation;
- 27 ppm: strong unpleasant odor, but not intolerable;
- 100 ppm: Coughing, eye irritation, loss of sense of smell after 2 to 5 minutes;
- 200 – 300 ppm: marked conjunctivitis (eye irritation) and respiratory tract after one hour of exposure;
- 500 – 700 ppm: loss of consciousness, cessation of respiration, and death;
- 1,000 – 2,000 ppm: unconsciousness at once, with early cessation of respiration and death in a few minutes; Death may occur even if the individual is removed to fresh air at once.

Source: Industrial Scientific Gas detection made easy 2014



Properties: Hydrogen sulfide is colourless and has the distinct odour of rotten eggs. The odour may be perceived at 0.003 ppm. At higher concentrations, the odour may not be detected due to olfactory fatigue. Because of this, a worker may be overcome by higher concentrations due to the fact they think the gas is gone, when in fact they have only lost the ability to detect it. Hydrogen sulfide is explosive in the range from 4.3 to 46 per cent.

Contamination limits: The eight hour average limit for hydrogen sulfide is 10 ppm, short term exposure limit is 15 ppm.

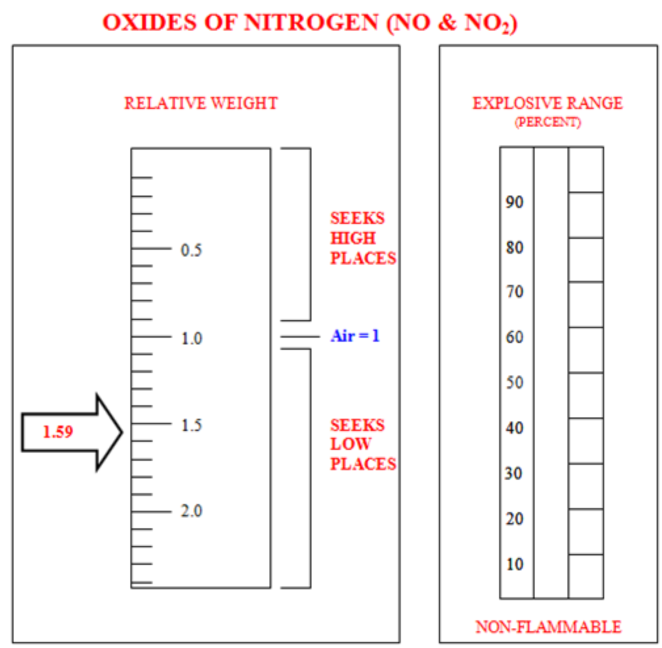
Detection methods: Electronic gas detectors and direct reading colorimetric tubes are the standard test methods for hydrogen sulfide.

Treatment of affected persons: Exposure to H_2S requires prompt treatment with antidotes and oxygen. This is administered by specially trained personnel in consultation with health care providers.

Nitrogen dioxide (NO_2)

Many deaths from fluid buildup in the lungs (pulmonary edema) have occurred from exposure to high concentrations of nitrogen dioxide. Nitrogen dioxide is relatively insoluble and that permits it to penetrate to the lower respiratory tract where it may cause death. There is a latent period of 3 to 30 hours from the time of initial exposure to the onset of potentially fatal pulmonary symptoms.

Origin: Burning or detonating of nitrate explosives produces nitrogen dioxide. Nitrogen dioxide is in the exhaust of diesel engines. However, diesel emissions are unlikely to create an emergency.



Health effects from exposure to nitrogen dioxide include:

- 5 – 10 ppm: Irritation to the nose and throat;
- 20 ppm: irritation to the eyes;
- 50 ppm: Maximum exposure for a 30 minute period; and
- 100 – 200 ppm: Tightness in the chest, acute bronchitis, and death from prolonged exposure.

Source: Industrial Scientific Gas detection made easy 2014

Properties: In its purest form, it is a reddish-brown gas with a pungent, acrid odour. The odour of nitrogen dioxide has been described as “sweetish and acrid” and “bleach-like”. It is detectable at 0.04 to 5 ppm. Nitrogen dioxide does not burn or explode.

Contamination limits: The eight hour average limit for nitrogen dioxide is 3.0 ppm (The Occupational Health and Safety Regulations, 1996). The limit when operating diesel engines underground is 2.0 ppm (The Saskatchewan Mines Regulations). The short term exposure limit is 5 ppm.

Detection methods: Direct reading colorimetric tubes and electronic gas detectors provide good detection for nitrogen dioxide.

Treatment of affected persons: Take the victim to fresh air. Give oxygen and complete rest. Seek medical help.

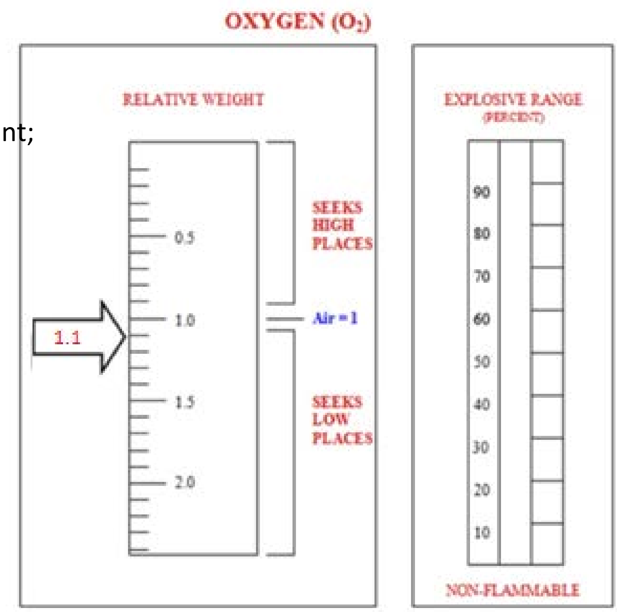
Oxygen (O_2):

Oxygen is essential for life. It is harmful to breathe air that is low in oxygen. Such air is known as an oxygen deficient atmosphere.

Origin: Potential causes of an oxygen deficient atmosphere include displacement by a gas other than air, and consumption of oxygen in a fire, explosion, or a chemical reaction. The rotting of organic material is a biological oxidation process that could lead to an oxygen deficient atmosphere by building up carbon dioxide. In the case of fires and explosions, there may be other toxic gases that will be harmful before the environment becomes dangerous due to oxygen deficiency.

Health effects and physiological responses from oxygen deficiency include:

- 17 per cent : impairment of judgement starts to be evident;
- 16 per cent: the first signs of anoxia appears;
- 12-16 per cent: breathing and pulse rate increases muscular coordination is slightly impaired;
- 10-14 per cent: Consciousness continues, emotional upsets, abnormal fatigue upon exertion, disturbed respiration;
- 6-10 per cent: nausea and vomiting, inability to move freely and loss of consciousness may occur; and
- < 6 per cent: convulsive movements and gasping respiration occurs; respiration stops and a few minutes later heart action ceases.



Source: Industrial Scientific Gas detection made easy 2014

Workplace Limit:

Oxygen should not be less than 19.5 per cent or more than 23 per cent by volume.

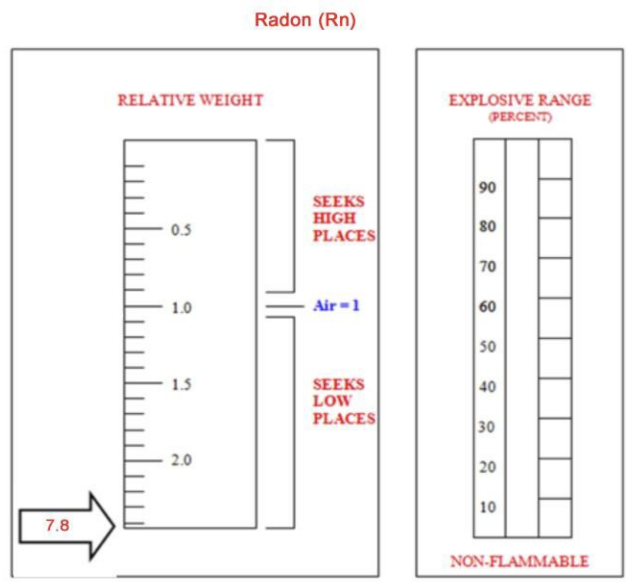
Properties: Oxygen is colourless, odourless and tasteless. Oxygen is not an explosive gas, but it does support combustion. In concentrations above 21 per cent, oxygen will produce accelerated combustion.

Detection methods: Electronic gas detection is a reliable detection method. Historically, oxygen deficiency was detected with a safety lamp. The flame of a candle or safety lamp is extinguished at approximately 16 per cent.

Treatment of affected persons: Take the victim to fresh air. Give oxygen and artificial respiration if breathing has stopped. Seek medical help.

Radon (Rn):

Health effects: Radon is not chemically toxic, but it is radioactive. Radon emits radiation and decays into a series of isotopes collectively called radon progeny, which are also radioactive. Comparatively, radon progeny provide higher exposure to radiation than radon itself. Radon is not immediately dangerous to life and health, but chronic exposures to elevated concentrations of radon and radon progeny have been associated with lung cancer.



Contamination limits: Mines licensed under the *Nuclear Safety and Control Act* (Canada) are required to ensure that exposures to radiation are in accordance with the *Radiation Protection Regulations* (Canada). Radon gas constitutes a small fraction of a Saskatchewan uranium miner's radiation dose, which is already well below the regulatory limits of 50 mSv/year and 100 mSv over a 5-year period.

Properties: Radon is a colourless, odourless and tasteless gas. Radon is not flammable and is chemically inert.

Origin: Radon is a radioactive decay product in the uranium decay series. As uranium is a naturally occurring element in the earth's crust, so too is radon. Radon will enter the mine atmosphere through the breaking of rock or the ingress of radon-bearing water. Once radon enters the mine atmosphere, ventilation is the best control to prevent the build-up of radon and radon progeny.

Detection methods: There are several different air samplers that can be used to measure radon and radon progeny. Also, personal dosimeters can be worn to monitor an individual's exposure to radon and radon progeny.

Treatment of affected persons: Continue to have routine medical examinations by a physician.

Ammonia (NH_3)

Origin: Ammonia is used as a chemical feed stock for fertilizer production. It is used in large air cooling units at some mines, and is also a primary ingredient in blasting agents like ANFO. Processing of uranium into yellow cake uses ammonia. Ammonia is found in US trona deposits, but the extent of the health risk is not known.

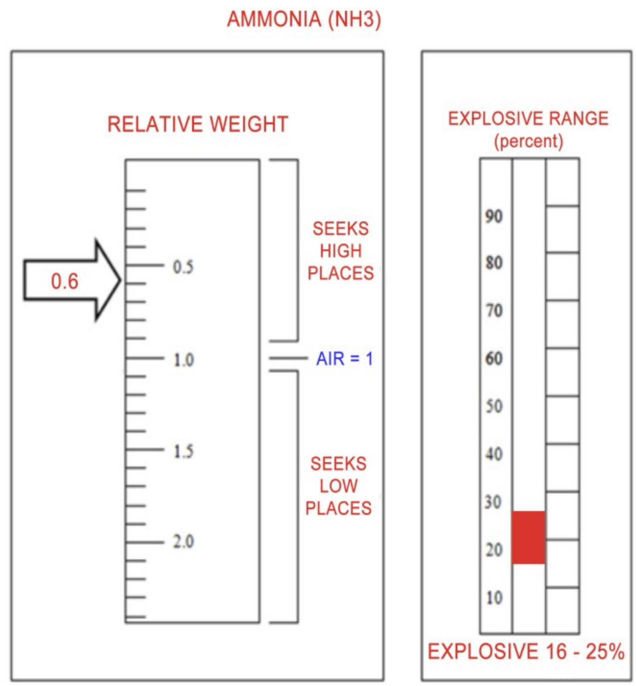
Health effects:

Ammonia is an alkaline chemical that is irritating to the eyes and moist skin. Severe irritation of the respiratory tract can lead to respiratory arrest. After an acute exposure, bronchitis or pneumonia may develop. Contact with ammonium hydroxide can cause extensive eye damage resulting in blindness. As with other compressed gases, there is a danger of frostbite from contact with the discharged gas near the point of discharge.

Some health effects of exposure to ammonia include:

- <25 ppm: minor irritation of the eyes and respiratory tract;
- 20-25 ppm: maximum concentration that does not produce severe complaints;
- 50-100 ppm: Swelling of the eyelids, conjunctivitis, vomiting, irritation of the throat; and
- 100 - 500 ppm: Concentrations are dangerously high, irritation becomes more intense; Death can result from highly concentrated prolonged exposure.

Source: Industrial Scientific Gas detection made easy 2014



Properties: Ammonia is flammable and colourless. It has a sharp or pungent, intensely irritating odour that is described as suffocating. The odour is detectable below 5 ppm. Ammonia has an explosive range of 16 to 25 per cent. In water, ammonia is known as ammonium hydroxide.

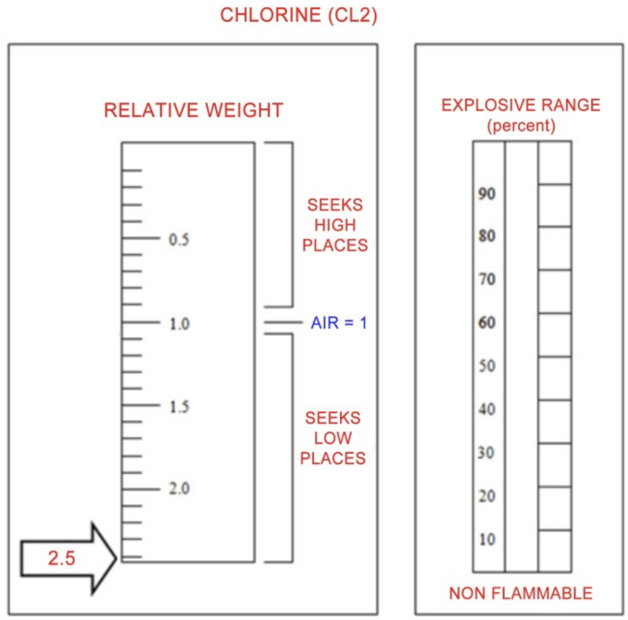
Contamination limits: The eight hour average limit for ammonia is 24 ppm. Short term exposure limit is 35 ppm.

Detection methods: The simplest way to determine ammonia concentration is with a direct reading colorimetric tube. Electronic gas detectors are available for the detection of ammonia.

Treatment of affected persons: Take the victim to fresh air and seek medical help.

Chlorine (Cl_2)

Origin: Chlorine is commonly used to treat potable water. In some cases, it may be used to treat effluent at a sewage treatment facility. Leaks can occur if piping or cylinders are damaged or if valves are improperly secured on a compressed gas cylinder.



Health effects:

Chlorine is a severe irritant for the skin, eyes and the upper respiratory tract. The inhalation of sufficient quantities of chlorine can cause bronchitis, fluid build-up in your lungs (pulmonary edema) and congestion. High doses of chlorine gas can cause rapid death. Exposure of the skin to chlorine leaking from compressed lines or cylinders can cause frostbite.

Health effects from exposure to chlorine gas include:

- 3 ppm: Irritations of the mucous membranes, eyes and respiratory tract;
- 3.5 ppm: produces an easily detectable odor;
- 15 ppm: Causes immediate irritations of the throat;
- 30 ppm: maximum exposure for 30 minute period; and
- 100 - 150 ppm: Pain, tightness in chest and death results from prolonged exposure.

  Source: Industrial Scientific Gas detection made easy 2014

Properties: Chlorine is non-flammable. It has a greenish yellow colour, and a distinct odour that smells like household bleach. The odour of chlorine can be perceived at 0.3 ppm.

Chlorine is an oxidizing agent and will react explosively or form an explosive compound when combined with substances like acetylene, ether, turpentine, ammonia, and hydrogen and fuel gas.

Chlorine gas is heavier than air and can collect in low lying areas when released into stagnant air. Chlorine gas released from a compressed gas cylinder or line is usually cold and thus is more likely to collect in low lying areas.

Contamination limits: The eight hour average limit for chlorine is 0.5 ppm, short term exposure limit is 1 ppm.

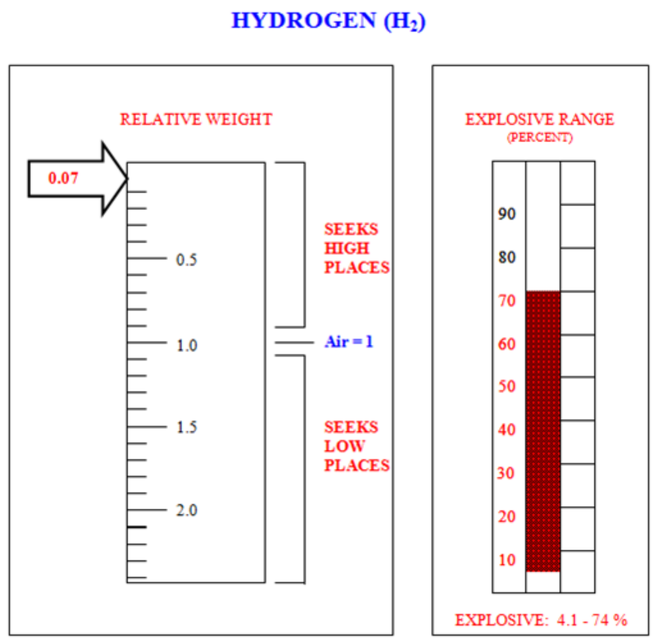
Detection methods: Direct reading colorimetric tubes are commonly employed to measure chlorine concentrations. Electronic gas detectors are also commercially available. However, some electronic chlorine detectors may require weekly maintenance to function properly.

Treatment of affected persons: Take the victim to fresh air, keep quiet and immediately seek medical attention. Give oxygen and provide artificial respiration as necessary.

Hydrogen (H_2)

Origin: Hydrogen gas may be released during a fire. However, such a release is rare. For example, it could occur during a steam explosion when molten metal causes water to break down into its elements of oxygen and hydrogen, or when combustible metals, such as magnesium, burn.

Can be released from batteries and should be considered in mobile equipment fires and near battery charging areas. It has also been found in sealed refuge stations due to leaky batteries.



Ultimately, hydrogen is very combustible and would be easily consumed by the blaze.

Health effects:

In high concentrations, hydrogen acts as a simple asphyxiant. The limiting factor is the available oxygen.

Properties: Hydrogen is colourless, odourless and tasteless. It is very flammable and explosive when exposed to heat or flame or when mixed with chlorine, air, oxygen, or other highly oxidizing or flammable materials. The explosive range is 4 to 75 per cent.

Contamination limits: There is no limit established for hydrogen. Because this gas is explosive, the lower explosive limit should not be exceeded.

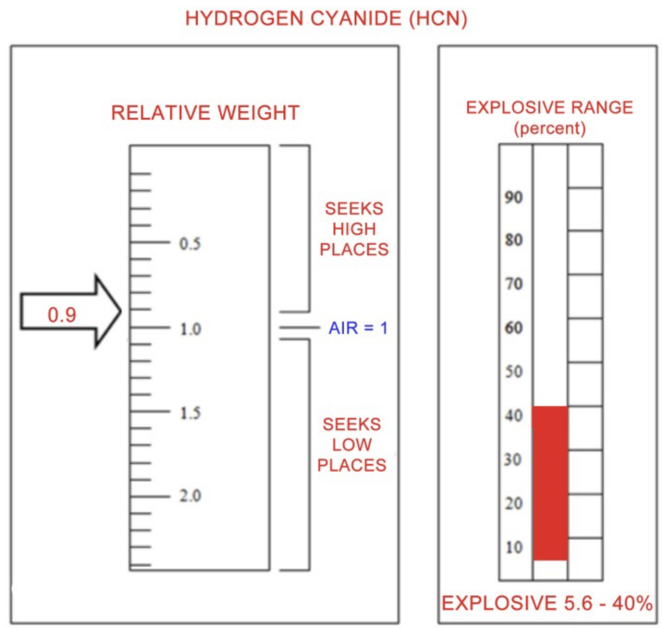
Detection methods: Electronic gas monitors with a combustible gas detector can be used to measure the concentration of hydrogen. Combustible gas detectors (catalytic diffusion sensors) are not gas specific and have different sensitivities to the various combustible gases. Ensure that the instrument is calibrated using the appropriate manufacturer’s conversion. Direct reading colorimetric tubes are also available for hydrogen.

Treatment of affected persons: Take the victim to fresh air. Give oxygen and provide artificial respiration as necessary. Seek medical help.

Hydrogen cyanide (HCN)

Origin: Cyanide compounds are commonly used in the recovery of gold. When cyanide is in a solution at a high pH, very small amounts of HCN are released. However, large amounts of HCN are released if the solution becomes acidic. Molten Sodium Cyanide mixed with water will result in an explosion and the release of HCN gas.

Health effects: Cyanide is highly toxic when inhaled as hydrogen cyanide gas or ingested as dissolved cyanide. Lethal amounts of cyanide can also be absorbed through the skin. The toxic effect is caused from interference with cellular metabolism. Cyanide in the blood blocks the use of oxygen by the body's cells causing death by asphyxia.
Upon its removal normal function is restored.



Health effects from acute exposure to hydrogen cyanide include:

- 10 - 50 ppm: Headache, dizziness, unsteadiness;
- 100 ppm: Feeling of suffocation, nausea;
- 100-200 ppm: death from exposure in 30 - 60 minutes; and
- 280 ppm: immediately fatal.

Source: Industrial Scientific Gas detection made easy 2014

Properties: Hydrogen cyanide is flammable and colourless. It has a faint odour of bitter almonds that may not be perceived by 20 to 40 per cent of the population. The odor threshold is 0.2 – 5 ppm.
Its explosive range is 5.6 to 40 per cent.

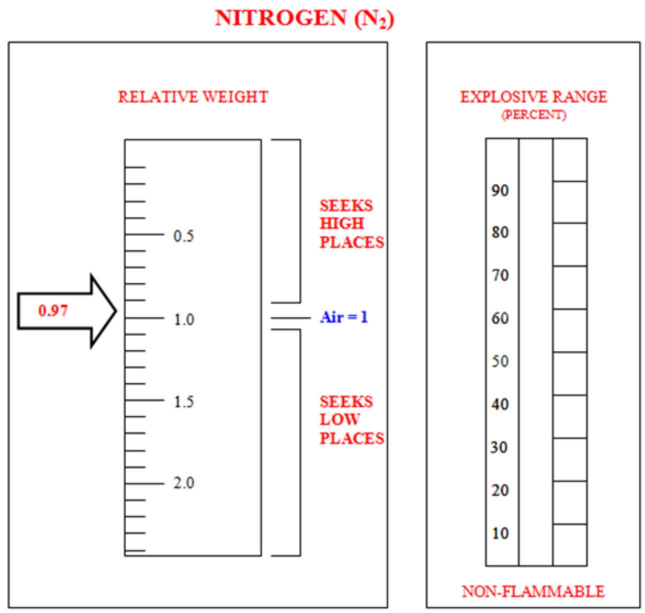
Contamination limits: The eight hour average exposure limit is 10 ppm, short term exposure limit is 4.7 ppm and the IDLH is 50 ppm. The Occupational Health and Safety Regulations*,* 1996 list a ceiling level of 4.7 ppm for skin exposure.

Detection methods: Electronic gas detectors and direct reading colorimetric tubes are available for testing for hydrogen cyanide. Colorimetric tubes require breaking an ampule and taking additional strokes in fresh air. This is a time consuming sample.

Treatment of affected persons: Rescuers should take special care to avoid contact with cyanide through contaminated skin, clothing, or mouth to mouth resuscitation. Take the victim to fresh air. Exposure to hydrogen cyanide requires prompt treatment with antidotes and oxygen. This is administered intravenously by specially trained personnel in consultation with health care providers. Send antidote with casualty as hospitals may not be equipped.

Firefighting: Responders must be equipped with appropriate PPE including SCBA. Always approach from upwind side. Do not use water. Water can release large amounts of HCN gas or cause an explosion. Do not use carbon dioxide extinguishers, use dry chemical extinguishing agents or dry sand.

Nitrogen (N_2):



Origin: Nitrogen is the largest component of normal air. Pure dry air at sea level contains 78.09 per cent nitrogen. Health effects: Nitrogen is nontoxic. At concentrations above 78 per cent, nitrogen is probably displacing oxygen. A lack of oxygen can result in asphyxiation.

Properties: Nitrogen is colourless, odourless and tasteless. Nitrogen is not an explosive gas and it will not burn.

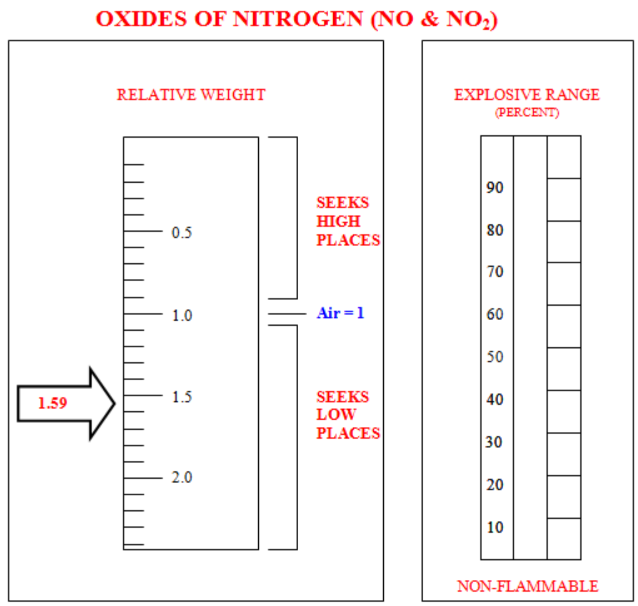
Contamination limits: There is no provincial standard. The oxygen concentration should not be lower than 19.5 per cent by volume.

Detection methods: Monitors and direct reading colorimetric tubes are not available. The relevant measurement method is to test for oxygen concentration.

Treatment of affected persons: Take the victim to fresh air. Give oxygen and artificial respiration if breathing has stopped Seek medical help.

Nitric Oxide (NO):

Origin: Nitric oxide is produced by burning or detonating nitrogen based explosives and by running diesel engines. Electric arc and oxy-gas welding will generate nitric oxide. Nitric oxide is also generated from an oxyacetylene torch because of the elevated operating temperature of 3093 °C to 3316 °C. Most of these sources of nitric oxide are workplace generated and do not generally cause mine emergencies.



Health effects:

- 0-50 ppm Low water solubility, therefore, only slight irritation of the mucous membranes is noted even though the TWA has been exceeded;
- 60-150 ppm Irritation is more intense, coughing and burning of the throat is evident; symptoms will clear if victim is removed relatively quickly to a clean air environment; and
- 200-700 ppm May be fatal even after short exposures.

  Source: Industrial Scientific Gas detection made easy 2014

There are few reports on the health effects of inhaling nitric oxide. Since nitric oxide spontaneously oxidizes in air and becomes nitrogen dioxide, the reported health effects are attributed to a mixture of nitrogen oxides that also includes nitrogen dioxide. However, based on animal studies, it appears that nitrogen oxide is much less toxic than nitrogen dioxide.

Properties: Nitric oxide is colourless and has an odour threshold of 0.3 ppm to 1 ppm. Nitric oxide has a slightly sweet odour.

Contamination limits: The eight hour average limit for nitric oxide is 25 ppm. Short term exposure limit is 38 ppm.

Detection methods: Direct reading colorimetric tubes and electronic gas detection equipment are available for determining the nitric oxide concentration.

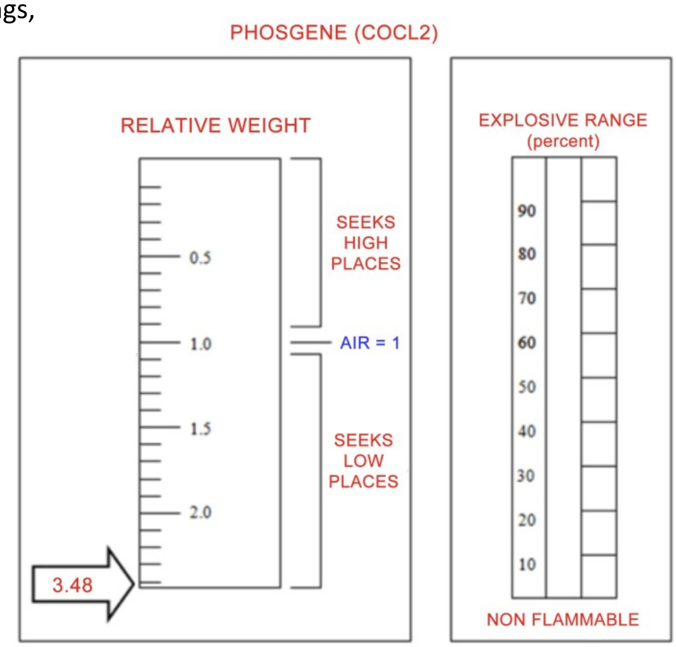
Treatment of affected persons: Take the victim to fresh air and seek medical help.

Phosgene ($COCl_2$)

Origin: Phosgene is used in the manufacture of a wide variety of organic chemicals. It is also used in metallurgy to separate ores by chlorination of the oxides and volatilization. Its chief importance, however, lies in its occurrence as one of the products of combustion whenever a volatile chlorine compound, such as chlorinated solvent or its vapour, comes in contact with a flame or very hot metal. This can produce a serious threat where ventilation is inadequate, the area is confined, or considerable quantities of chlorinated vapours are involved.

Health effects:

Phosgene is very irritating to the entire respiratory tract. A single shallow breath of a moderately high concentration causes a rasping, burning sensation in the nose, pharynx and larynx. The most serious effect of phosgene is lung irritation causing increasing edema until as much as 30 per cent to 50 per cent of the total blood plasma has accumulated in the lungs, causing "dry land drowning." High concentrations of phosgene are immediately corrosive to lung tissue and result in sudden death by suffocation.



Health effects of exposure to phosgene include:

- 1 ppm: maximum amount for prolonged exposure;
- 1.25-2.5 ppm: dangerous to life, for prolonged exposure;
- 5 ppm: cough or other subjective symptoms within one minute;
- 10 ppm: irritation of eyes and respiratory tract in less than one minute;
- 12.5 ppm: dangerous to life in 30-60 minutes;
- 20 ppm: severe lung injury within one to two minutes;
- 25 ppm: dangerous to life after as little as 30 minutes;
- 90 ppm: rapidly fatal (30 minutes or less).

Splashes of phosgene in the eye will produce severe irritation, and phosgene on the skin can cause severe burns.

Properties: Phosgene is a colourless gas that decomposes in water. It has a suffocating musty hay odour.

Contamination limits: The eight hour average exposure limit is 0.1 ppm, short term exposure limit is 0.3 ppm.

Detection methods: Direct reading colorimetric tubes are available for phosgene.

Treatment of affected persons: The person should be removed from the contaminated atmosphere and given oxygen. Any exposure must be treated as life threatening. The person should be kept at rest and delivered to medical aid as soon as possible.

Sulphur Dioxide (SO_2):

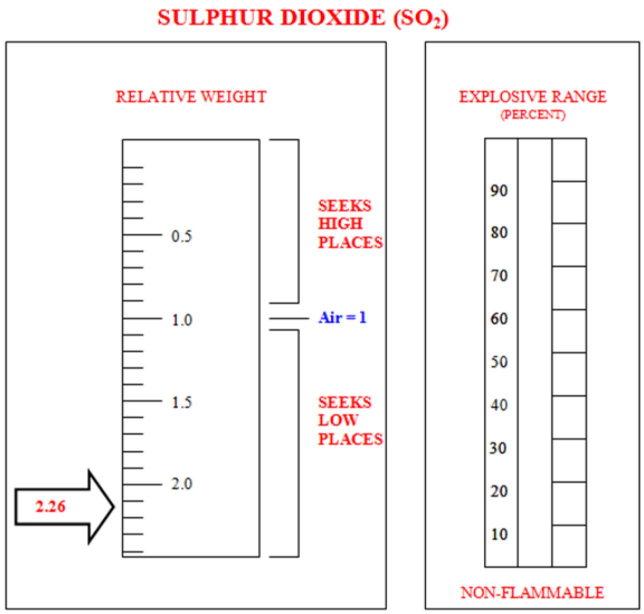
Origin: Sulphur dioxide may be produced when blasting sulfide ores. It is the main gas released from conventional copper and zinc refineries that use oxide roasters and reverberatory furnaces.

Health effects: Sulphur dioxide is an irritant to the eyes and the upper respiratory tract. The major effects of the gas are on the upper respiratory tract. In high concentrations edema of the lungs or glottis may occur. Respiratory paralysis can also occur at high concentrations.

Health effects from exposure to sulphur dioxide include:

- 0.3–1 ppm Sulfur Dioxide initially detected by taste;
- 3 ppm Odor becomes easily detectable;
- 6–12 ppm Irritation of the nose and throat;
- 20 ppm Irritation of the eyes;
- 100 ppm Maximum exposure for a 30 minute period; and
- 400–500 ppm Dangerous concentration can cause edema of the lungs and glottis and death from prolonged exposure.

  Source: Industrial Scientific Gas detection made easy 2014



Properties: Sulphur dioxide is colourless with an irritating, pungent, strong suffocating odour. The threshold for smell or taste is 0.3 to 1 ppm.

Contamination limits: The eight hour average limit for sulphur dioxide is 2, the short term exposure limit is 5 ppm.

Detection Methods: An electronic gas detector or direct reading colorimetric tube can be used to measure the concentration of sulphur dioxide.

Treatment of affected persons: Take the victim to fresh air. Give oxygen and artificial respiration if breathing has stopped. Seek medical help.

Combustible gases

Several gases are used in Saskatchewan mining operations that are hydrocarbon fuels. The more common of these gases are methane (CH_4), propane (C_3H_8) and acetylene (C_2H_2). Methane is also found in coal beds where it is formed by the decomposition of organic material.

Health effects: The combustible gases referred to in this section are considered nontoxic. However, they act as simple asphyxiants. See the health effects for oxygen, these gases may also be explosive depending on their concentrations in the atmosphere.

Contamination limits: There are no limits established for the combustible gases of acetylene, methane and propane. Because these gases are explosive, the lower explosive limit should not be exceeded. Phosphine occurs in commercial grade acetylene. Therefore, acetylene should be limited to 3160 ppm to limit phosphine to 0.3 ppm (The Occupational Health and Safety Regulations, 1996).

Properties: Methane, propane and acetylene are flammable and colourless. Methane is the major component of natural gas. Both propane and natural gas sold commercially have an odorant added to make the gases easy to smell. Acetylene has a garlic-like odour.

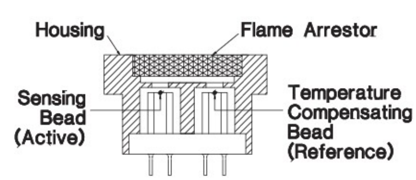
Examples of Flammable Ranges

Fuel	Lower Limit (%)	Upper Limit (%)
Gasoline Vapour	1.4	7.6
Methane (Natural Gas)	5.3	15.0
Propane	2.2	9.5
Hydrogen	4.0	75.0
Acetylene	2.5	93.0

Table 1.1 Flammable gasses.

Origin: Leaks from compressed gas vessels or their piping network are the most likely sources of combustible gas. Methane can be produced when organic material rots in stagnant water. Methane occurs as free gas in coal beds. Its presence is a particular concern in underground coal operations. If gas concentrations and sources of ignition are not controlled, disasters, such as the Westray explosion, can occur.

Detection methods: Electronic gas monitors with combustible gas detectors are most commonly employed to evaluate these gases. Combustible gas detectors are not gas specific and have different sensitivities to various combustible gases. Ensure that the appropriate manufacturer's conversion factor is applied and the instrument is appropriately calibrated. Direct reading colorimetric tubes are also available for these gases.



Combustible Gas Sensor

Catalytic diffusion sensors are the most widely used devices for the detection of combustible gases and vapors. These sensors start with wire being wound into coils. These coils are then doped with two types of catalysts: one to make the element active and one to make it blind. These different coils are then matched into pairs of reference and sensing elements. This forms a combustible gas sensor.

This sensor then has a fixed voltage applied across both elements, causing them to heat up to very high temperatures. The sensor is also connected to a balanced resistance, a Wheatstone Bridge, which detects changes in the resistance of the sensor elements. When a combustible gas comes in contact with the sensor, the active element begins to burn the gas causing it to increase the temperature. The temperature of the reference element remains unchanged because it is incapable of burning gas. The increased heating of the active element causes an unbalance in the circuit and this is interpreted as a positive combustible signal.

Because combustion is taking place within the sensor chamber the sensor must be designed and built in such a way that it is intrinsically safe and will not act as an ignition source in the event it is exposed to a combustible atmosphere.

Important: Because the LEL sensor is actually measuring low levels of combustion there needs to be sufficient oxygen present. Any time there is less than 10 per cent oxygen the LEL detector cannot be considered to be accurate. Consideration must be given to the effect of adding additional oxygen to the potentially explosive atmosphere.

Treatment of affected persons: Take the victim to fresh air. Give oxygen and provide artificial respiration as necessary. Seek medical help.

Gas	8 hour average contamination limit (ppm)	15 minute contamination limit (ppm)	IDLH (ppm)
Ammonia	24	35	300
Butane	1,000	1,250	
Carbon dioxide	5,000	30,000	40,000
Carbon monoxide	25	190	1.20 0
Chlorine	0.5	1	10
Gasoline	300	500	
Hydrogen chloride	Ceiling 2		50
Hydrogen Cyanide	Ceiling 4.7		50
Hydrogen Sulfide	10	15	100
Nitrogen dioxide	2 (Sask Mine Regs)	5	20
Nitric oxide	25	38	100
Oxygen	195,000		
Phosgene	0.1	0.3	2
Phosphine	0.3	1	50
Sulphur dioxide	2	5	100

Table 1.2 Saskatchewan contamination limits.

	Gas	Chemical Symbol	Specific Gravity	Explosive range	Colour	Odour	Taste
Lighter than air	Hydrogen	H_2	.07	4 – 75	None	None	None
	Ammonia	NH_3	0.6	16 – 25	None	Pungent	None
	Methane	CH_4	0.6	5 - 15	None	None	None
	Hydrogen cyanide	HCN	0.9	5.6 -40	None	Bitter almonds	None
	Acetylene	C_2H_2	0.9	2.5 – 93	None	Garlic	None
	Carbon monoxide	CO	0.97	12. 5 – 74	None	None	None
	Nitrogen	N_2	0.97	Non flammable	None	None	None
	AIR		1				
Heavier than air	Oxygen	O_2	1.1	Non flammable	None	None	None
	Hydrogen sulphide	H_2S	1.19	4.3 - 46	None	Rotten eggs	Sweet
	Hydrogen chloride	HCL	1.3	Non flammable	None	Pungent & Irritating	None
	Carbon dioxide	CO_2	1.53	Non flammable	None	None	Acid
	Propane	C_3H_8	1.5	2.2 – 9.5	None	Gassy	None
	Nitrogen dioxide	NO_2	1.59	Non flammable	Reddish Brown	Pungent acrid	Blasting powder
	Sulphur dioxide	SO_2	2.26	Non flammable	None	Pungent	Acidic (bitter)
	Chlorine	CL_2	2.5	Non flammable	Greenish Yellow	Bleach like	None
	Phosgene	$COCL_2$	3.48	Non flammable	None	Musty Hay	None
	Radon	Rn	7.8	Non flammable	None	None	None

Table 1.3 Gas properties chart.

Chapter Two – Respiratory Protection

Limitations

Chemicals that can penetrate the skin are not normally found underground, but the Mine Rescue Team must know what the dangers are at a specific site. Respiratory protective equipment will not protect people from gases that can enter the body by means other than the respiratory tract.

If there is any potential for harm from skin exposure to chemicals additional protection such as a Haz-Mat suit will be required over and above respiratory protection.

An oxygen supplying apparatus is the most important piece of equipment that mine rescue personnel will use. An inadequate face to face piece seal needlessly exposes the wearer to toxic gases in the environment. One of the common causes of inadequate face seals is facial hair.

Therefore, persons wearing full face piece, self-contained respirators must be clean-shaven. Respirators have limited space for eye glasses. The use of prescription lenses in frames fitted inside the face piece is recommended for workers needing corrective lenses. The use of contact lenses inside a self-contained breathing apparatus face piece is not recommended, however *NFPA 1500* does allow as long as the wearer can successfully demonstrate a history of long term use.

Respiratory Hazards

The three most common ways poisons enter the body are through the:

- Digestive system (ingestion);
- Skin (absorption); and
- Respiratory system (inhalation).

The respiratory system is the quickest and most direct way for poisons to enter the body because it is closely associated with the circulatory system and is constantly supplying oxygen to every cell in the body.

Respiratory hazards can be classified as follows:

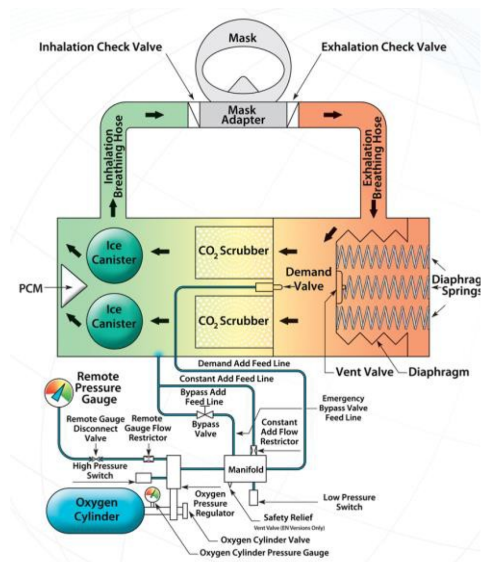
- Oxygen deficiency;
- Gas and vapour contaminants;
- Particulate contaminants (aerosols, including dust, fog, fumes, mist, smoke and spray); and
- A combination of gas, vapour and particulate contaminants.

General respiratory protective device classifications

Respiratory protection devices fall into three classes:

- Air-purifying;
- Air-supplied; and
- Self-contained breathing apparatus.

Non-self-contained or air purifying respirators remove contaminants from the air before they are inhaled. These devices do not supply oxygen to the user and cannot be used in oxygen deficient atmospheres. Air purifying respirators use cartridges or filters that remove particulates, vapours or gases from the inhaled air.



Self-contained Breathing Apparatus (SCBA): open-circuit SCBA provides breathing air through the use of compressed air cylinders or an attached airline. The exhaled air is exhausted to the outside atmosphere.

Closed-circuit SCBA (re-breathers): a closed system that removes the carbon dioxide from the circulatory system of the apparatus and provides fresh oxygen to the air before it is re-breathed.

The self-contained respirators are totally independent of the outside atmosphere.

Breathing Techniques

To use respirators or other breathing devices properly, the art of deep breathing should be practiced until it becomes a habit. The value of slow, deep breathing at all times can be demonstrated by doing an exercise that causes panting or quick breathing. Draw in several deep, controlled breaths, slowly and evenly, inhaling as much air as possible. The normal rate of breathing can be resumed quickly and easily this way without panting.

When breathing devices are worn, heat and breathing resistance must be expected. The heat may vary from normal to an intolerable temperature, depending upon the type of apparatus and local conditions. The resistance can vary from slight to as much as three or four psi, and must be overcome.

If the wearer is breathing fast, he will be unable to overcome the resistance and get enough air before starting to exhale. When this happens, the wearer gets “air hunger.” This causes a feeling of suffocating, and an urge to remove the breathing device at all costs.

It is essential to breathe deeply and slowly when wearing any breathing device. This habit can only be acquired by continual practice.

Self-contained breathing apparatus (SCBA)

Physiological effects of breathing pure oxygen:

The quantity of oxygen consumed by the body varies with the amount of energy expended (see Figure 2.1). A person at rest uses approximately one cubic metre of air per hour (m^3/hr).

During strenuous exercise, the consumption of air may increase to more than 8 m^3/hr but the body uses no more oxygen than it requires.

Pure oxygen breathed by someone wearing a self-contained breathing apparatus causes no noticeable ill effects, even after several successive periods of use. The only exception to this rule is if the wearer is subjected to air pressures greater than the normal atmospheric pressure of 1.01 bar (14.7 psi) such as might be encountered in caisson work, or for continuous exposure for 24 to 48 hours.

The human body uses the following approximate amounts of oxygen in litres per minute (lpm) based on various workloads.	
Rest	0.2 to 0.5 lpm
Light work	0.75 to1.0 lpm
Moderate work	1.0 to 1.5 lpm
Heavy work	1.5 to 2.0 lpm
Extremely heavy work	2.0 to 3.0 lpm

Figure 2.1 Human metabolic oxygen requirements

Elimination of dangerous amounts of carbon dioxide in apparatus

One of the most important functions of any closed-circuit, self-contained breathing apparatus is the elimination of carbon dioxide in the air that is to be re-breathed.

In a self-contained, open-circuit, pressure-demand type of apparatus using compressed breathing air, the exhaled air passes through a valve to the outside air.

In a closed-circuit, self-contained breathing apparatus the exhaled air is reused, therefore the carbon dioxide produced by breathing must be removed from it and oxygen added to it.

This is usually accomplished by passing the exhaled air through a canister containing a CO_2 absorbent. Oxygen consumed in breathing is replaced from a cylinder contained in the apparatus.

The CO_2 absorption process produces heat that raises the temperature of the canister and the air flowing through it.

A self-contained, closed-circuit oxygen-producing (chemical) apparatus removes carbon dioxide by a chemical reaction with potassium dioxide (KO_2) that consumes the carbon dioxide and produces oxygen.

Self-Contained Breathing Apparatus (SCBA closed-circuit)

The primary SCBAs used in Saskatchewan mine rescue are the Drager BG-4 and the Biomarine 240R. These units are service rated for 4 hours (240 minutes) of operation. They are both positive pressure, closed-circuit respirators that can be worn in oxygen deficient or toxic atmospheres. These SCBAs will recirculate the exhaled breath scrubbing it of carbon dioxide and replenishing the oxygen.

No matter what apparatus is being used, always refer to the manufacturer's instruction manual for use.

Donning bench and bench tests of breathing apparatus

Immediately before using any closed circuit breathing apparatus, the wearer is required to do a bench test. This assures the wearer that the apparatus is safe. If the wearer is not satisfied that the apparatus is working properly, he should report to the person in charge for repair or replacement of the apparatus. Under no circumstance should a team member begin a mission using an apparatus that has not been tested and passed all the pre use tests.

As a user, your life depends on the proper functioning of your breathing apparatus. In an underground situation there is no quick easy escape if your apparatus fails.

Station checks of breathing apparatus

Self-contained breathing apparatuses must be station tested at intervals according to manufacturer recommendations, after each use and after lengthy transport over rough terrain to ensure their readiness for emergency response.

The main tests performed to ensure the safe operation of a breathing apparatus are for air tightness and function of the working parts.

Any malfunctions or deficiencies found on any apparatus must be repaired immediately. The unit must be taken out of service until repaired. The results of the station checks must be recorded in a logbook.

Other regular inspections of the apparatus should be done according to the manufacturer's recommendations.

Regular maintenance and storage of breathing apparatus should be done according to the manufacturer's recommendations.

Important: Oil or other petroleum based lubricants must not be used on any oxygen apparatus, particularly on the high-pressure connections or the cylinder valve. Failure to observe this precaution may lead to an explosion.

Care must be taken to ensure that when the apparatus is stored, it is protected against dust, sunlight, heat, extreme cold, excessive moisture, damaging chemicals and mechanical damage. Do not store rubber, neoprene or silicone parts under fluorescent lights.

Facemasks should be stored in a normal position so that the sealing edge is not distorted.

Reference dates of the Carbon Dioxide absorbent should be checked and recorded to make sure their shelf life is not exceeded.

Charging oxygen cylinders

Wherever oxygen breathing equipment is used, the empty oxygen cylinders have to be recharged. The obvious method is to pass oxygen from one cylinder to the other through a pressure-tight tube or cascading. A system has been adopted that enables the small apparatus cylinders to be recharged by equalizing their pressure with that of large cylinders. This "cascade" system incorporates a specially designed manifold that is connected to a series of three or more large cylinders. Cylinders should be secured to prevent their falling. A cascade system may also be used with a high pressure oxygen booster pump.

Recharging instructions: Arrange the three cylinders so that the one with the lowest pressure is to the right as you are facing them, and the one with the highest pressure is on the left. Connect cascade fittings to the cylinder outlets. To recharge the small cylinder, the following procedure should be used:

1) Connect the small cylinder to the adapter and open the small cylinder valve; be sure the bleeder valve is closed before the small cylinder valve is opened. Open the adapter valve.
2) Slowly open the valve on the right-hand cylinder, and close it again as soon as all sound of the flow has stopped.
3) Repeat with the valve on the centre cylinder.
4) If necessary, repeat with the valve on the left-hand cylinder; close the valve on the small cylinder then the adapter valve.
5) Open the bleeder valve.
6) Disconnect small cylinder.
7) Mark with chalk or masking tape the pressure of the cylinder and the time it was filled.

Important: Open all valves slowly to prevent excessive heat generation.

High pressure oxygen booster pumps

With the cascade system, it is difficult to attain the desired charging pressure of more than 2200 PSI. This can best be achieved by compressing oxygen and transferring it from one cylinder to another at the desired higher pressure with multi-valve piston-type pumps. These pumps are available in either hand-operated or power-driven models.

Note: Follow the complete operating and maintenance instructions in the manuals supplied with the booster pumps.

Masterline Oxygen Booster pump

Important: No oil or grease of any kind should be used in any type of high-pressure oxygen pump. A chemical reaction between the oil or grease and any oxygen is very likely to result in a violent explosion.

Use lubricant according to the manufacturer's instructions. The lubricant that can safely be used in these pumps is a mixture of one part glycerin and four parts water.

As there are many different pump manufacturers, and they all have different pumping specifications it is important to always refer to the manufacturer's instruction manual.

SCBA Cylinders

To identify their contents, compressed gas cylinders are distinctively coloured and marked. Breathing air cylinders are painted various colours and have the words "pure breathing air" stenciled on them. Oxygen cylinders are usually green, white or silver and are marked "oxygen."

The purity of the oxygen used in rescue apparatus is very important because impurities tend to accumulate in the circulatory system of the apparatus. The CSA Standards specifies that compressed breathing oxygen shall meet the purity requirements of Canadian Military Standard.

MSHA (Mine Safety and Health Administration) specifies that oxygen for use in rescue apparatus shall contain at least 98 per cent oxygen, no hydrogen, and not more than 2 per cent nitrogen, with traces of argon. Oxygen made by liquefaction processes conforms to this standard and contains no impurities other than nitrogen, with traces of the rare, inert gases.

The use of medical grade oxygen is recommended due to its lower moisture content. In addition, compliance with the CSA Standard requires that compressed oxygen not be used in supplied air respirators or in open-circuit, self-contained breathing apparatuses that have previously used compressed air. As well, oxygen must never be used with airline respirators.

All cylinders used to transport oxygen and other non-liquefied gases whose pressure exceeds 29 kPa at 21^{o}C must comply with the strength requirements of the Ministry of Transport Canada.

All such cylinders exceeding 30 cm in length must also have valves equipped with an approved safety device (bursting disc).

All cylinders that have an outside diameter of five centimetres or more must be retested by hydrostatic pressure at least once every five years. The date of retesting must be marked on the cylinder.

Deterioration of air or oxygen cylinders

Air and oxygen contain small amounts of moisture that are generally transferred from large cylinders to small cylinders during refilling. The moisture hastens oxidation of the metal of the cylinder, causing scale, sediment, and rust and pitting, and eventually weakens the walls of the cylinder. These changes occur with no visible sign on the outside of the cylinder. Hydrostatic pressure is the only means by which the condition of the cylinder can be determined. When the cylinder is subjected to a hydrostatic pressure, the "elastic expansion" (total expansion minus permanent expansion) is determined.

Oxygen cylinders which are usually charged to 204 atmosphere (3000 psi) are tested to 300 atmosphere (4400 psi).

Safe practices with oxygen cylinders

All cylinders should be held securely in the apparatus. The constant motion of an emergency vehicle during emergency response could create a dangerous situation if oxygen cylinders are not secured in place by straps, or some other type of fixture.

Summary of Do's and Don'ts when working with oxygen cylinders

Do:

- Wear appropriate PPE;
- "Crack" cylinder valve prior to attaching regulator by opening slightly and then closing again; this procedure blows dust and debris out of the cylinder valve opening;
- Open cylinder valves slowly;
- Keep regulator inlet filter clean and intact to prevent lint from collecting on the valve seat; replace as required;
- Replace worn or frayed valve seat inserts; they are much more likely to catch fire;
- Have repairs done by qualified personnel;
- Keep soap away from high pressure connections because it is flammable; and
- Pressure test (hydrostatic test) all steel oxygen tanks over a certain size at least once every five years; all tested tanks have the date stamped on them.

Do Not:

- Disconnect the cylinder before depressurizing the system;
- Use oil or grease on oxygen equipment; an explosion may occur;
- Smoke or use open flame near oxygen (oxygen vigorously supports combustion);
- Use regulators and equipment that have been used with other gases; flammable residues may remain in these regulators;
- Use cylinders for hat trees or clothes racks; if there is a leaky connection, hanging clothes may easily ignite;
- Use quick connect or cam lock connectors on high pressure systems. It can create an explosive situation if released under pressure; and
- Fill any cylinders if there is any damage or defects noted.

Chapter Three - Ventilation

General Information

Mine ventilation systems are unique in that the ventilation is needed at continually changing work faces that are gradually moving away from the source of fresh air. This requires continuous changes to mining ventilation systems.

Purpose & principles of ventilation

A typical ventilation system is designed to supply sufficient fresh air to the mining faces, shops, warehouses and all other work areas in the mine.

The ventilation system must reduce or control the working temperature, the level of dust, and diesel emissions in the air to provide adequate working conditions. The ventilation system must also maintain the temperature in the shafts above freezing.

The condition and performance of the ventilation system must be constantly assessed and recorded. Regulations require an adequate quantity of good air to be supplied in a mine. Workplace air must contain at least 19.5 per cent oxygen.

The ventilation system must exhaust contaminants and harmful gases and/or dilute them to acceptable limits. Large quantities of air are required to dilute carbon monoxide and other gases given off by diesel engines underground. Concentrations of diesel gases must not exceed 25 ppm for carbon monoxide, 5,000 ppm for carbon dioxide, and 2 ppm for nitrogen dioxide.

Any diesel engine used underground must have at least 3.8 m^3 of ventilation air per minute for each rated kilowatt. The ventilation system must supply enough air flow to cool workers and prevent heat stress. Heat from engines, motors, equipment, lighting etc. must be carried away from the work areas in the mine.

The rate of ventilation, conveniently measured in cubic metres of air per second (m^3/sec), should meet three requirements:

- Sufficient air movement throughout the mine to prevent the formation of pockets of stale, stagnant air;
- Sufficient fresh air to limit the level of air pollution from all sources in the mine; and
- Lower air temperature and humidity to limit heat stress.

Ventilation conditions

Mine ventilation can be further examined in two forms that can exist.

Normal mechanical ventilation:

In mechanical ventilation, air is supplied and controlled through fans and ducting. Generally, most underground mines in Saskatchewan have similar ventilation systems. These systems use:

- Low pressure, high volume supply fans located on the surface mine air heaters for winter conditions distribution fans located underground to direct and distribute air to all work areas; and
- Low pressure, high volume fans on the surface to exhaust mine air and contamination from the mine.

Natural ventilation

In this form, air flow assumes a natural circuit, which may be determined through air temperatures, air pressures, and elevation.

Mine fire situation:

This is a third situation that is not normal. In this form, the use of normal mechanical ventilation may have been interrupted. Air flow through normal or natural ventilation could be affected by the fire with ventilation reversals and unpredictable ventilation effects.

Effects of fires on ventilation

The ventilation system in a mine is critical in a mine fire or gas inflow emergency.

All of the work done designing an effective ventilation system by proper fan placement, installation of doors and stoppings and using negative ventilation to extract exhaust air cannot be counted on during a fire. Experience has shown that fires in main travel ways containing power supplies, ventilation doors etc., will drastically change the airflow. If heat is sufficient bulkheads and doors can be damaged, electrical substations or even power or control cables can be damaged shutting down ventilation fans. The mine rescue teams and the command center must never assume the ventilation is normal until proper readings have been taken by the teams.

In underground mining, a fire or inflow of toxic gases can become a problem by quickly spreading deadly gases throughout the whole mine. Air flow speeds of up to 22 KPH are not uncommon in Saskatchewan mines.

Anyone downstream of a fire could have very little time to react and secure safe refuge from the fire or smoke source. With the large size of some mines it could still take a long time for products of combustion to complete the ventilation circuit. Even though you may only have minutes for the ventilation to clear a hard rock mine with as much as 1 million cfm, a gas might need from 6 to 8 hours to travel from the downcast shaft to the up cast shaft in a potash mine due to the distances.

Mine fires produce gases and heat which the ventilation system transports through the mine, the gases can be poisonous or explosive, and the heat can cause ventilation disturbances with unstable airways or airflow reversals.

Ventilation changes in a mine fire situation should not be carried out until all people underground are accounted for or the effects are known. Although every safety precaution is taken to prevent the occurrence of mine fires, the possibility of mine fires will always exist.

The greatest hazards of mine fires are the noxious gases produced by combustion. These noxious fumes are carried by the ventilation air currents throughout the mine. In order to combat this hazard and design safe escape routes and firefighting activities, the paths along which combustion products are carried by the mine ventilation system must be known.

Prediction of the air flow distribution in a mine after a fire is as complicated as the fire itself. The magnitude of the ventilation disturbances depends on a variety of factors existing in the mine. Unexpected air flow reversals are known to have caused large mine disasters. In shallow mines, the ventilation disturbances are usually less than in deep mines.

Fundamentals of air flow

Air flow is determined by temperature and pressure differences. Air flows from high pressure areas to low pressure areas and, in a mine, is caused by pressure differences between intake and exhaust openings.

Air flow follows a square-law relationship between volumes and pressures. In order to increase the volume of air flow two times, four times the pressure must be exerted.

Assessing air flow

Assessing the direction and volume of air is an important function of the Mine Rescue Team because knowing the velocity and the cross-sectional allows the quantity of air flow to be calculated. Knowing the direction and velocity of air flow allows one to check whether the ventilation system is functioning as it should be, including:

- Whether the fans are on;
- The condition of the seals, line brattice, or ventilation tubing;
- The condition or the position of doors and regulators;
- The condition of the air lines or the position of the airline valves; and
- Short circuits or recirculation of air currents.

Three instruments commonly used to measure air movement are:

- Velometer;
- Anemometer; and
- Smoke tube.

Velometers and anemometers are used to measure medium and high velocity air movement (above 2.5 metres per second).

Smoke tubes are more suitable for measuring very slow-moving air (below 2.5 metres per second) and determining the direction of the flow.

Since testing the mine atmosphere is time consuming, it is a good idea to involve as many members of the team as practical to perform this task.

Important: A record should be kept of all the tests, times and the locations where the tests were taken. All team members must be kept informed of the conditions of the atmosphere in which they are working.

Pressure losses

Resistance to air flow can be caused by rough ground, restricted openings, and travel over long distances. Shock losses can also increase the resistance to air flow. Shock losses are caused by abrupt changes in the velocity of air movement. They are the result of changes in air direction or of airway area, obstructions, and regulators. Anything that causes turbulence can decrease air flow.

Splitting air currents

Air will tend to follow the path of least resistance. Dividing the mine ventilation system into multiple splits provides separate ventilating districts in the mine which permits easier air control.

Natural splits are those where the airflow divides naturally. Each split handles a volume of air dependent on the pressure drop and resistance factor for that circuit.

Regulated splits are those where it is necessary to control the volumes in certain low-resistance splits to ensure adequate air to flow into the splits of higher resistance.

A regulator is an artificial resistance installed in a low-resistance split. They may be small openings in stoppings controlled by slide doors or may be doors latched partly open.

Leakage losses

Air leaking from the fresh air side to the exhaust side is considered a leakage loss. Leakage losses in any mine ventilation system will be influenced by the number and condition of brattices, bulkheads, and controls along its length.

Leakage losses seriously reduce the efficiency of a mine ventilation system. A leakage path is simply a parallel return path to the fan. The amount of leakage is determined by the pressure difference between intake and return and the condition of stoppings, doors, air splits and brattice.

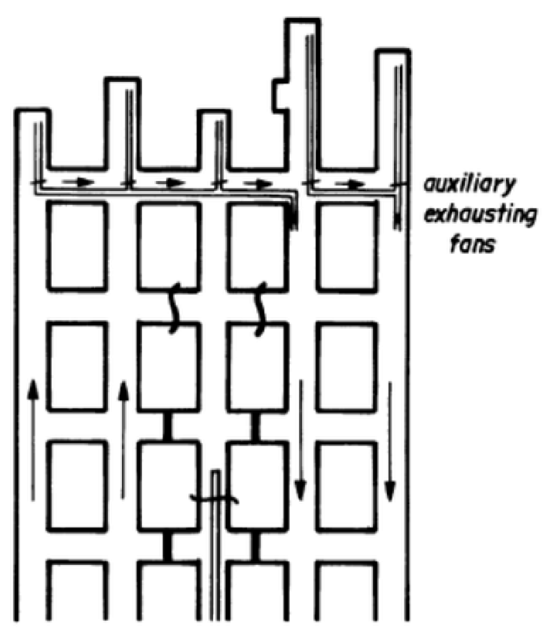
In potash mines, each brattice separating the supply side from the exhaust side will leak an amount determined by the quality of the installation. This may be a few cubic metres per second or more and this leakage can greatly affect ventilation control in both normal mining operations and in mine fire situations.

Consideration must be given to leakage losses when planning how to ventilate smoke from an area as the smoke can recirculate at every point of leakage.

Important: All ventilation equipment must be maintained and kept in good order for an efficient ventilation system.

Auxiliary ventilation

The practice of redirecting the main ventilation system with smaller local fans is termed auxiliary ventilation. Auxiliary ventilation is needed because workplaces in mines are continually moving away from the main ventilation air stream.



There are a number of common applications of auxiliary ventilation, but they all may be grouped into three categories:

1. Supplying air to both development and production dead-end workplaces (quantity control)

2. Supplying uncontaminated air to workplaces with contaminated air (quality control), or

3. Supplying conditioned air to faces of workplaces in uncomfortably hot or cold environments (temperature-humidity control)

Ventilation of dead-end workplaces is the most frequent and important application of auxiliary ventilation. It is employed for both development and exploration in potash, coal and metal mining.

In most large potash mines this is handled by continually boosting the positive pressure along the path of the ventilation stream with additional fans. Because this airflow cascades from one working face to the next, the practice of splitting the main air flow into multiple drifts allowing it to slow down so that dust is allowed to settle, then redirecting into a single stream again to boost the velocity prior to ventilating the next working face is used.

In uranium mines the radon gas cannot be allowed to travel from one working face to another, so a negative ventilation system is designed to capture any exhaust at each working face and direct it straight into the exhaust air stream.

Any area with only one entrance will likely require auxiliary ventilation. This could include drifts, raise, stopes, shafts, sumps, etc. that are in development or do not have flow through capabilities.

Situations requiring auxiliary ventilation for quality-control purposes may arise in uranium mines because they produce radon gas. Radon gas is maintained within allowable limits by a combination of extraction and dilution ventilation. In uranium mines, it is generally necessary to vent contaminated air directly to the surface. Air contaminated by radon gas cannot be allowed to flow from a contaminated workplace to an uncontaminated workplace.

Methods of auxiliary ventilation

Supplying air to dead-end workplaces is the common denominator in auxiliary ventilation systems. This is normally done by moving fresh air to a workplace using ducts. Where there are multiple openings into a workplace, fresh air can be directed to the working face through one opening and returned through an adjoining opening. Connecting cross-cuts allow the air to flow between openings.

A major inconvenience with any method of auxiliary ventilation during development is the necessity of frequent extension. The auxiliary air stream must be delivered as close as possible to the face so that it can sweep away the impurities generated there.

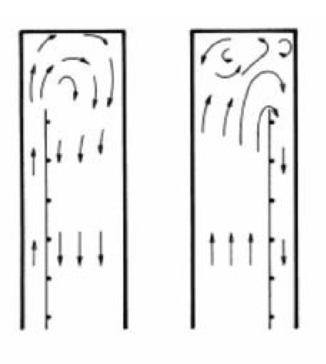
The two main methods of ventilating the faces of dead-end workplaces are:

- Line-brattice with air entering on one side of the brattice and returning in the other side; and
- Fan and ventilation pipe or tubing.

The first is used in potash mines, while the other is employed principally in hard rock mines.

Line-brattice

Putting up a plastic curtain lengthwise in an entry or a room effectively divides that opening in two. If the brattice is erected from the last cross-cut to within a few feet of the

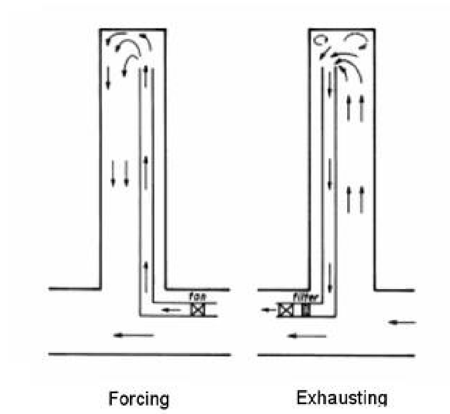


working face, ventilating air can be directed to the face along one side of the brattice and returned along the other side. A line-brattice is usually constructed of fire-resistant plastic hung from posts, crosspieces, spads or hangers in the roof. Plastic sheeting, a nonporous material, is now being used in place of brattice cloth. In line-brattice operation, air velocity is lost because of leakage to or from the exhaust side. These leakages are a major concern.

As well as airflow limitations, line-brattices can also slow the passage of workers and machines through a work area. Even in a wide underground passage, the brattice is installed off centre to allow room for the passage of mobile equipment.

Fan and ventilation pipe

The use of fans attached to vent pipes or tubing is the most common method of auxiliary ventilation for dead-end workings.



Fan locations

Fans are used in mining for fresh air supply, removing exhaust air or both. Fan locations in a mine are generally determined by the style of mining. Large supply fans are usually on the surface while distribution fans are normally located throughout the major work areas. Smaller fans provide airflow in individual work areas.

Booster fans

Booster fans can be located in long airways to boost the airflow volume. Booster fans can be free standing and used to siphon or jet air along a travel way without using bulkheads. The high outlet velocity of the booster creates excess momentum and exerts a forward force on the normal airflow.

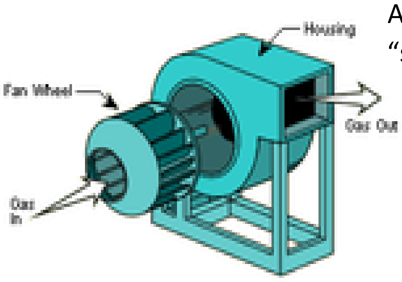
In Saskatchewan, booster fans are mainly used in potash mines.

Fan types

Axial flow fans

Are generally high volume, low pressure fans that can be either directly driven by the motor shaft, with the motor inside the tube body, or remotely driven through the use of belts with the motor outside the tube body. They are generally adjustable for volume by setting the pitch of the adjustable blades on the rotor and, in some cases, motor speed can be tailored to adjust volume and pressure.

Centrifugal fans



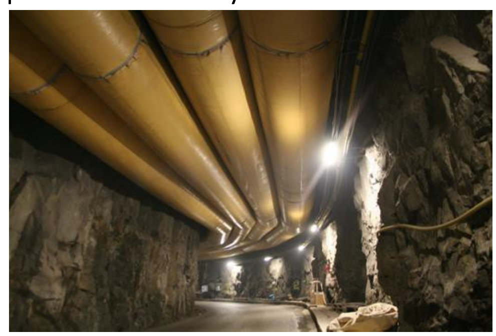
Are generally high pressure, low volume fans which consist of a multi-bladed, “squirrel cage” wheel in which the leading edge of the fan blades curve toward the direction of rotation. They have low space requirements, low tip speeds, and are relatively quiet.

Another Common fan in some mines is air driven from a compressor line. It is often used in stopes and raises where electricity is not available and used in emergency situations for ventilating and can be small enough to be carried by hand or very large.

Fan installation

Proper field installation will improve a fan's air delivery. If practical, set the discharge and rotation of the fan so that the discharge is in the direction desired. Ideally fans should be located away from side walls for easy inspection and service and the ducting should have as few elbows and obstructions as possible. Often they are hung near the back and against the wall to allow for equipment to pass. Generally, this is on the right hand side when entering the heading so as not to interfere with the operator's compartment on most mobile equipment. The fan must be located such that air pushed out of the heading is not sucked back in (recirculation). Ducts should be of sufficient diameter and leak free. A poor duct system can detract from the performance of any fan.

Vent tubing



Tubing of various sizes and materials is used extensively in some mines. Tubing made with fire resistant material will help reduce the risk of fire.

The advantage of tubing is the ability to direct airflows to specific or selected areas. It is relatively light and easy to install, is flexible and it can withstand blast concussion. A common application of tubing is to attach it directly to a fan's discharge, and route the air to the desired location.

For temporary use such as emergency ventilation it can be laid on the floor or sill. If the end tubing whips or flaps it can be slightly choked off to create a small back pressure.

Barricades and seals

Barricades and seals are used as a means of directing or diverting airflow to a desired area at a mining face. In potash mines, brattice is commonly used as a means of separating fresh air from return air (back fill and muck stops are also used). In hard rock mines, posting and frame work is used to support brattice seals. Barricades and seals can also be made from wood, Styrofoam, belting, shotcrete or cement blocks.

Brattice can be ordered in various dimensions. Attaching a brattice to the sides and back of a potash mine is done by using spads, air powered nailers, or powder-actuated tools.

Airflow calculations

At most mines, airflow is calculated in cubic feet per minute (cfm, or ft3/min); cubic metres per minute (m3 /min); or cubic metres per second (m3/sec).

To calculate airflow:

- Measure the height and width of the drift; and
- Multiply these two numbers to obtain the drift's area (A=h x w).

Measure the speed the air is moving. This should be done in an area of the drift with no obstructions, taking an average across the entire drift. If the sample is taken in only one spot the results will be inaccurate due to natural differences in the airflow in a drift. Therefore it is best to take an average of multiple readings or use the averaging function on most anemometers.

- Multiply the air speed by the area of the drift; and
- The equation is: area x air speed = volume per unit time.

As an example: A drift 3 metres high and 10 metres wide with an air speed of 20 m/min has an airflow of: (3 m x 10 m) x 20 m/min=600 m^3/min

Use of measuring instruments

Smoke tube kit

A smoke tube kit consists of a handheld rubber aspirator bulb, two rubber plugs, and smoke producing tubes.

To measure airflow over a certain distance (eg. 3 m):

1. Insert a smoke-producing tube into the exhaust fitting of the aspirator bulb.

2. Squeeze the plastic tube to break glass ampoules inside tube. When these ampoules are broken, two different chemicals in the tube form an aerosol smoke as air is passed through the tube.

3. Squeeze the aspirator bulb to emit smoke and observe the direction and time it takes the smoke to travel the predetermined distance.

4. When finished, remove the aspirator bulb and install rubber plugs on the ends of the tube.

Velocity (speed) of air = distance travelled/time.

Hence if it takes 20 seconds for the smoke to travel 3 m, we obtain:

Velocity = 3 m/20 sec = 0.15 m/sec or 9 m/min

Velometer/Anemometer

A velometer or anemometer measures the velocity of air. A velometer will be of the vane or thermal type. Various manufacturers have devices that operate on one of these basic principles. Vane anemometers are relatively simple. The movement of air spins the fan blades. The rotational motion is calibrated to the air velocity, and associated electronics compute the air velocity. The volumetric rate may be computed when the cross-sectional area of the drift is known.

Thermal anemometers use either a heated thermocouple or a hot wire and associated electronics to determine the velocity and volumetric rates. Most errors are made by operators not familiar with their operation or misinterpretation of volume rates.

Caution: Both types of instruments are relatively accurate. However, very low air velocities cannot be determined with any degree of confidence. Both types of

Figure 3-1

anemometers are sensitive to rough treatment and are easily damaged.

Velocity and Volumetric Rates:

If the volumetric flow rate is required, the cross-sectional area of the passageway must also be known. The cross-sectional area is multiplied by the velocity determined by the instrument. If the velocity is measured in feet per minute, the cross-sectional area is determined in square feet, and the volumetric flow rate is in cubic feet per minute (cfm). If the instrument reads velocity in metres per second, the cross-sectional area of the drift is calculated in square metres and multiplied by the velocity to calculate the cubic metres per second (m^3/sec). The average velocity is determined by taking several readings across the drift.

An anemometer is used for measuring velocities from 40 to 610 metres per minute. The individual uses the anemometer to measure the airflow for at least one minute and up to two minutes. The average air speed during the measurement period would then be recorded.

Chapter Four - Mine Fires

Mine fires are much more common than most people realize. Most fires in underground mines are small and quickly extinguished. Disasters caused by mine fires are less frequent. Any mine fire could, however, become a major disaster if not quickly brought under control.

Underground mine fires pose hazards that may be greatly magnified when compared to a similar fire in a surface situation. Heat, smoke and steam cannot be easily dissipated or rise into the atmosphere. They are confined to the same area that the workers fighting the fire are in. Heat and gases commonly spread up wind against the normal ventilation so that even approaching from the up wind side does not ensure safety. Ground conditions deteriorate as it is heated and as it cools after the fire is out. Low head room restricts the distance from which water can be used. There is no escape through a window if things go wrong.

Fire knowledge

Everyone who works underground in a mine should have a basic understanding of what fire is and how fires are best controlled. Knowledge of fire and the hazards of mine fires will encourage every underground worker to do his or her part to prevent fires.

Workers must be trained to take the appropriate action if they discover a fire. The health and safety of workers cannot be left to chance. Fortunately most fires are discovered early and are quickly brought under control. The early discovery of a fire, however, is just a matter of chance and the lives and jobs of underground workers are much too important to be left to chance.

Considerations upon locating fires

A worker discovering a fire must consider several possible actions very quickly. Any action taken, or not taken, will have a big effect on the fire and on the safety of everyone in the mine.

If you discover a fire in a mine, do you:

- Attempt to put it out? How do you attack the fire and how long should you try?
- Sound an alarm? How?
- Attempt to get out of the mine? By what route?
- How do you notify workers in your area?
- Should you shut off burning electrical motors? How?
- Should you shut off fans? Close or open ventilation doors?

It is much better to make informed decisions on the basis of understanding the situation than to leave the wellbeing of the workers and the mine to chance. Knowing what to do if a fire is discovered is important. Knowing how to prevent fires is even better.

Each mine must develop specific emergency procedures for its site. All employees must be well trained in those emergency procedures and understand how to apply them. The proper response to alarms should be practised at least once a year. All fire equipment must always be kept in proper working condition.

Availability of firefighting equipment

There are many sources of reference for determining the location of handheld extinguishers or other firefighting equipment underground.

The Mine Regulations*, 2003* set out the following locations for underground mines:

- At each headframe or other entrance to the mine;
- In each hoist room;
- At any surface location that a fire may create a hazard to a worker;
- On each vehicle and at each stationary diesel engine; and
- At every underground crusher station, electrical installation, pump station, conveyor belt drive, shops and fuel bays, explosives and flammable storage areas and any area involving hot work.

NFPA 10 also provides guidance for the placement of extinguishers throughout the mines and the workplaces. While many factors are taken into consideration when determining the hazard classification and minimum extinguisher size, as a general rule in a structure the maximum travel distance to an extinguisher for a Class A hazard is to be no more than 75 feet. In a building equipped with fire hose cabinets they can replace one half of the above required extinguishers. For Class B hazards, this maximum distance would be reduced to 50 feet, but the use of water to eliminate half of the extinguishers is not applicable.

It is obviously not practical to install extinguishers throughout the long travel ways in a large mine to meet these requirements, but these guidelines should still be followed in high hazard areas such as underground shop facilities and fuel and oil storage areas.

For the mounting of extinguishers, NFPA 10 gives the following guidance: Extinguishers need to be mounted in such a way that they are easily accessible and protected from corrosion. If an extinguisher weighs less than 18 kg it must be mounted such that the top of the extinguisher is no more than 1.5 m from the floor. If it weighs more than that it can be no more than 1.07 m from the floor. At no time can an extinguisher be less than 102 mm from the floor. If an extinguisher is allowed to sit on the floor it will be subject to corrosion.

For enclosed areas, it is recommended that the extinguisher be placed near the exit, possibly even outside the exit. This allows the worker to retreat to safety then re-approach while ensuring safe egress. This also makes the extinguishers more likely to be available to ER persons as opposed to it being on the other side of the fire.
Extinguishers must be inspected on a monthly basis by a competent person. During the inspection the following are to be verified:

- Location in designated place;
- No obstruction to access or visibility;
- Pressure gauge reading or indicator in the operable range or position;
- Fullness determined by weighing or hefting;
- Verifying that operating instructions on nameplates are legible and face outward;
- Checking for broken or missing safety seals and tamper indicators; and
- Examination for obvious physical damage, corrosion, leakage, or clogged nozzle.
  **NFPA 10*

Training

Even though a workplace is fully equipped with the appropriate fire extinguishers the chance of successfully extinguishing a fire in the early stages are only increased if the work force is trained in the appropriate techniques.

Training must include the following:

- Classification of fires;
- Identifying the extinguisher ratings and capabilities; and
- Application techniques.

Experience shows that to be truly beneficial, the training should include the practical hands on use of all types of extinguishers that are used at the site.

Summary of general underground emergency fire procedure

Whoever discovers a fire must take prompt action. The following is a generic emergency procedure for an underground mine fire.

Important: Safety must be the top priority at all times.

If the fire is large and/or obviously cannot be quickly controlled:

1. Sound the alarm by the established means.

2. Warn the workers in your area.

3. Begin evacuation.

If an incipient or small fire is found, then the following actions should be immediately taken to contain or extinguish it:

- Use water and Class A extinguishers on Class A fires and the smothering approach for Class B and Class C fires;
- The current must always be turned off in an electrical fire and an attempt should never be made to extinguish it with a stream of water;
- Approach the fire from the upwind side and be very careful when using the smothering type of extinguisher in a confined space;
- After a fire extinguisher is used, it must always be returned for recharging and its use reported; and
- If, after a few moments, definite progress is not made or it becomes clear the fire cannot be contained, follow #1.

Important: Always remember that deadly gases are constantly being produced and workers must not be exposed to these gases or other hazards, such as explosions, weakening timber and deteriorating ground. These gasses may act different than expected as the fire will be looking for oxygen and will be exhausting extreme heat. It is important to not assume that because workers are upstream from a fire that the smoke and gasses will not travel against the normal vent stream.

Every fire, no matter how small, must be reported at once as it may have released deadly gases into the mine air. Once put out, the fire area must be monitored until re-ignition is impossible. Depending on the material that was on fire this may require a long term fire watch to ensure re-ignition is not possible.

Any unusual occurrences in the mine should be noted and reported at once. This could be the smell of smoke or odors, clouds of dust, air blasts, sudden changes in ventilation, power failure. Any of these signs could mean that something irregular or dangerous has happened, and that the life of the workers could be endangered and quick action may be required.

Fire description

Fire or burning is a form of rapid oxidation of a substance that produces much heat and light energy. The release of heat energy in a fire may be so rapid as to cause an explosion (a violent expansion of the gases produced).

Oxidation is the chemical reaction combining oxygen with another element or compound. This reaction is almost invariably accompanied by a release of heat energy. The amount of heat energy released depends on the oxidizing (burning) compounds. Among the hottest heat energy releases are those occurring when oxygen combines with carbon, hydrogen, or a compound of both elements.
If the chemical combination of carbon and oxygen is complete, carbon dioxide, a colourless gas, is produced. If hydrogen and oxygen combine, water vapour or steam is produced. If the chemical 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 combustion is incomplete, the products of combustion are carbon monoxide, carbon dioxide, water vapour, and particles of free carbon, and the resulting smoke is grey or black. When fighting a fire rescuers will encounter incomplete combustion at some point. Consideration must be given to the toxic gasses being produced.

Sources of heat

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 low the temperature. The speed of the molecules increases when any matter is heated. Anything that sets the molecules of a substance in motion is producing heat in that substance. There are five general sources of heat energy:

- Chemical;
- Electrical;
- Mechanical;
- Solar; and
- Nuclear.

Chemical heat energy

Chemical heat energy is rapid oxidation or combustion. Substances capable of oxidizing rapidly are known as combustibles. The most common of these substances 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. Some combustibles are capable of self-generating temperatures which 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 to dissipate the heat before combustion takes place. Spontaneous ignition occurs when combustion heat is not sufficiently dissipated.

Electrical heat energy

Electrical energy can produce enough heat to start fires 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 so that a spark is discharged from body to body. This spark may not be hot enough or last long enough to ignite ordinary combustibles. However, it may ignite flammable liquid, vapour or 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 often generates sufficient heat 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.

Mechanical heat energy

One source of mechanical heat energy is friction or the resistance to motion of two bodies rubbing together. Another source is produced by 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.

In mines, a more common occurrence of mechanical heating can be found when the bearings seize or the brakes lock on a moving vehicle. Small fires from such sources are quite common.

Solar heat energy

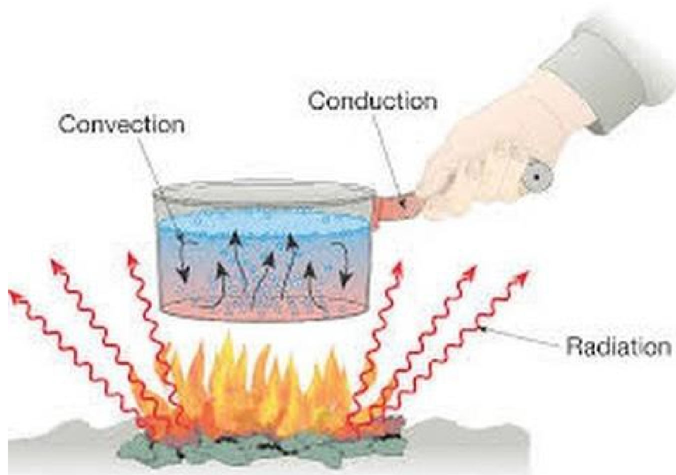
The energy transmitted from the sun in the form of electromagnetic radiation is known as solar heat energy. Typically, solar energy is distributed fairly evenly over the face of the earth and, in itself, is not really capable of starting a fire. However, when solar energy is concentrated on a particular point, as through the use of a lens, it may ignite combustible materials.

Nuclear heat energy

The release of very large quantities of energy from the nucleus of an atom is known as nuclear heat energy. Nuclear heat 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.

Heat transfer

A number of the laws of physics explain the transmission of heat. One, the Law of Heat Flow, says heat tends to flow from a hot substance to a cold substance. The colder of two bodies in contact will absorb heat until both objects are at the same temperature.



Heat can travel by one of three methods:

- Conduction;
- Convection; and
- Radiation.

The following sections describe how this transfer takes place.

Conduction

Heat may be conducted from one body to another by direct contact of the two bodies or through another heat-conducting medium. For example, one end of a metal rod will become heated when the other end is placed in a fire. The amount of heat that will be transferred and its rate of travel depend upon the conductivity of the material through which the heat is passing.

Not all materials have the same heat conductivity. Aluminum, copper and iron are good conductors, however, fibrous materials such as felt, cloth and paper are poor conductors. Liquids and gases are poor conductors of heat because of the movement of their molecules. Air is a relatively poor conductor.

Convection

Convection is the transfer of heat by the movement of air or liquid. For example, as air near a steam radiator becomes heated (by conduction), it expands, becomes lighter and moves upward. As the heated air moves upward (convection), cooler air takes its place at the lower levels.

Fire spread by convection moves mostly in an upward direction because heated air in an area will expand and rise. However, air currents can carry heat in any direction. Convection currents are usually the way heat is transferred from one area to another.

Although often mistakenly thought to be a separate form of heat transfer, direct flame contact is actually a form of convective heat transfer. When a substance is heated to the point where flammable vapours are given off, these vapours can be ignited, creating a flame.

Radiation

Heat energy can travel in waves or rays from one area to another as radiation. Like light, radiant heat 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.

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

Radiated heat is one of the main ways fires spread. Immediate attention is required at points where radiated heat is severe. When fires produce flames of large size and volume, radiated heat can ignite nearby combustibles.

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.

The Burning Process

Elements of a Fire

In reviewing the rapid oxidation process known as combustion, we note that three factors are necessary for a fire:

- A combustible material;
- The presence of oxygen or an oxidizing agent; and
- Enough heat to increase the temperature of the combustible material to its ignition temperature.

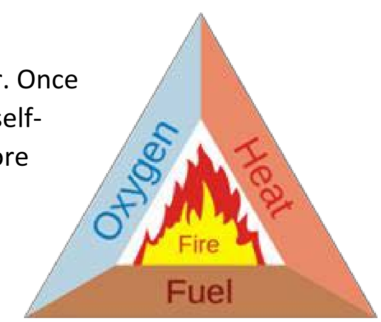
Fire burns in two ways

- Smoldering (surface); or
- Flaming combustion.

The smoldering (surface) mode of combustion is represented by the fire triangle (fuel, heat and oxygen). The flaming mode of combustion, such as the burning of logs in the fireplace, is represented by the fire tetrahedron (fuel, temperature, oxygen and the uninhibited chemical chain reaction).

The Fire Triangle

These three factors, fuel, oxygen, and heat, have been incorporated into the simple fire triangle model:



The fire triangle is used to explain the components necessary for burning to occur. Once combustion has begun, with ample supply of fuel and oxygen, a 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 the factors from the three sides of the fire triangle are present.

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

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

Cooling:

Cooling reduces the temperature of the fuel to below its ignition temperature.

One of the most common ways to put out fire is by cooling it with water. The process of extinguishing by cooling depends on cooling the fuel to a point where it does not produce sufficient vapour to burn. Solid 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 as vapour production cannot be reduced sufficiently. Lowering the temperature is dependent on the application of enough flow in proper form to establish a negative heat balance.

Smothering:

Smothering is used to prevent oxygen from reaching the fire by:

- Displacing the air with an inert gas;
- Sealing the fire off within an inert blanket of foam; and
- Smothering the fire in some other way.

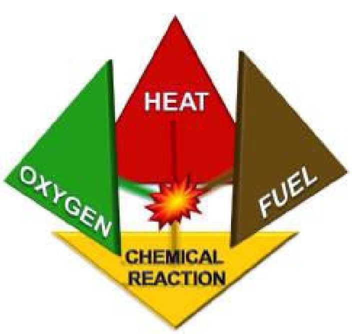
Extinguishment by oxygen dilution means reducing the oxygen concentration in the fire area. This can be done by introducing an inert gas into the fire or separating the oxygen and the fuel. This method of extinguishment will not work on self-oxidizing materials or on certain metals that are oxidized by carbon dioxide or nitrogen (the two most common extinguishing agents).

Separation:

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, or by removing solid fuel in the path of the fire. Another method of fuel removal is to allow the fire to burn until all fuel is consumed.

The fire tetrahedron

In addition to the fire triangle, the fire tetrahedron is a four-sided figure, similar to a pyramid, with the four sides representing fuel, heat, oxygen and uninhibited chemical chain reaction (Figure 4-2).



There are many by-products from fire. These can include carbon monoxide (CO), carbon dioxide (CO_2) and sulphur dioxide (SO_2). The flammable by-products can combine with oxygen and burn, thus feeding the chemical chain reaction of combustion and contributing to the chain that expands the fire. The vapours that are produced in a fire may also be combustible and contribute to the fire.

Hazards from burning materials

The health hazard from exposure to the thermal decomposition (burning) process depends on the particular material involved and the decomposition temperature. These materials could include such things as tires, conveyor belting, electrical equipment and cables, styrofoam, brattice. Gases and smoke produced in fires involving material can be acutely toxic or severely irritating to the respiratory tract. Decomposition products may include hydrogen cyanide, hydrogen chloride, aldehydes, nitrogen oxides, phosgene and heavy smoke (particulate). Refer to SDSs to find information on hazards specific to a material.

About 10 per cent of all fire deaths are unexplained by carbon monoxide poisoning or other clear causes. They include deaths with signs and symptoms of respiratory tract irritants. Such irritants prevent proper breathing (i.e. choking, suffocation) and impede escape, thus increasing exposure to asphyxiants such as carbon monoxide and hydrogen cyanide.

Other than for carbon monoxide, it is difficult to assess the acute health risk of exposure to fire decomposition products. There is not one degradation product that can be used as an index for the toxicity of the smoke. Smoke from fires involving plastic material should be considered more toxic than smoke produced by burning wood or fossil fuel.

Extinguishment by chemical flame inhibition

Some extinguishing agents, such as Halon and certain dry chemicals, interrupt the flame producing chemical reaction, resulting in rapid extinguishment. This method of extinguishment is effective only on gas and liquid fuels as they cannot burn in the smoldering mode of combustion.

If extinguishment of smoldering materials is desired, cooling will also be necessary.

Principles of fire behaviour

Fuel may be found in any of the three states of matter:

- Solid;
- Liquid; or
- Gas.

Only gases burn. Burning liquid or solid fuel requires its conversion to a gaseous state by heating. Fuel gases are evolved from:

- Pyrolysis for solid fuels and gases; and
- Vaporization for liquids.

This is the same process as boiling water to evaporate it, and water in a container evaporating in sunlight. In both cases, heat causes the liquid to vaporize.

Generally, the vaporization process of liquid fuels requires less heat than does the pyrolysis for solid fuels. This limits the control and extinguishment of liquid fuel fires because their re-ignition is much more likely.

Gaseous fuels can be the most dangerous because they are already in the natural state required for ignition. No pyrolysis or vaporization is needed for combustion. Gaseous fuel fires are also the most difficult to contain.

Solid fuels

Solid fuels have a definite shape and size that significantly affects how efficiently they catch fire. Of primary consideration is the surface-to-mass ratio, that is, the ratio of the surface area of the fuel to the mass of the fuel. As this ratio increases, the fuel particles become smaller and more finely divided (i.e., sawdust as opposed to logs), and the ease of ignition increases tremendously. As the surface area increases, the ease and rate of combustion increases. If a log that may burn slowly is ground to wood dust it can burn at a rate we would consider explosive.

The physical position of a solid fuel is also of great concern to firefighting personnel. If the solid fuel is in a vertical position, fire will spread more rapidly than if the fuel is in a horizontal position. The speed of fire spread is due to increased heat transfer through convection as well as conduction and radiation.

Liquid fuels

Liquid fuels have physical properties that increase the hazard to personnel because they are harder to put out. A liquid, like a gas, assumes the shape of its container. When a spill occurs, the liquid will assume the shape of the ground (flat), flowing and accumulating in low areas.

The specific gravity of a liquid is determined by comparing the weight of the liquid to the weight of water. This is similar to gases being compared to air. Water is assigned a specific gravity of 1, therefore, liquids with a specific gravity less than one are lighter than water, while those with a specific gravity greater than one are heavier than water.

If a liquid also has a specific gravity of one, it will mix evenly with water. It is interesting to note that most flammable liquids have a specific gravity of less than one. This means that if a firefighter is confronted with a flammable liquid fire and flows water on it improperly, the whole fire may just float away, igniting everything in its path.

The solubility of a liquid fuel in water is also an important factor. Alcohols and other polar solvents dissolve in water. If large volumes of water are used, alcohols and other polar solvents may be diluted to the point where they will not burn. As a rule, hydrocarbon liquids (nonpolar solvents) will not dissolve in water and will float on top of water. This is why water alone cannot wash oil off our hands; the oil does not dissolve in the water. In addition to the water, soap must be used to dissolve the oil.

Consideration must be given to which extinguishing agents are effective on hydrocarbons (insoluble) and which affect polar solvents (soluble). Today, multipurpose foams are available that will work on both types of liquid fuels.

The volatility, or ease with which a liquid gives off vapour, affects fire control. All liquids give off vapours to some degree in the form of simple evaporation. Liquids that give off large quantities of flammable or combustible vapours are dangerous because they may be easily ignited.

Gases

Specific gravity is also used when comparing the density of gas or vapor in relation to air. Specific gravity is of concern with volatile liquids and gaseous fuels. Gases tend to assume the shape of their container but have no specific volume. If a vapor is less dense than air (air is given a value of one), it will rise and tend to dissipate. If a gas or vapor is heavier than air, it will tend to hug the ground and travel as directed by terrain and wind.

It is important for all firefighters to know that every hydrocarbon except the lightest one, methane, has a vapor density greater than one and will sink and hug the ground, will flow into low-lying areas. Hydrocarbons are very dangerous for that reason. Common gases such as ethane, propane and butane are examples of hydrocarbons gases that are heavier than air.

Fuel-to-air mixture

Once a fuel has been converted to a gaseous state, it must mix with an oxidizer to burn, usually oxygen. The mixture of the fuel vapour and the oxidizer must be within the flammable limits for the fuel. That is, there must be enough, but not too much, fuel vapour for the amount of oxidizer.

If there is too much fuel vapour, the mixture is too rich to burn. If there is not enough, it is too lean to burn.

The flammable limits of how rich or lean a fuel vapour mixture can be and still burn are recorded in handbooks and are usually reported for temperatures of 21^{o}C. These are referred to as the lower explosive limit (LEL) and the upper explosive limit (UEL). These limits change slightly with temperature.

Oxygen

Is contained in the air and will support combustion in any fuel. The air we breathe contains approximately 21 per cent oxygen (20.94 per cent).

When oxygen content is reduced to 16.25 per cent or lower, flames are extinguished.

Some fuels contain sufficient oxygen in their makeup to support combustion themselves (i.e., celluloid, explosives).

Pure oxygen is an intense supporter of combustion.

OILS or GREASES sometimes burst into flames or explode in the presence of COMPRESSED OXYGEN.

Smoke and gases

Smoke consists of gases and finely divided solids. It may be combustible and even explosive under some conditions (e.g., a sudden inrush of air from opening of a door). During a fire, smoke and gases rise, therefore by keeping close to the floor, air is more breathable.

Of the various gases associated with fire, you will probably be most concerned with carbon monoxide, a product of incomplete combustion. Common usage of polyvinyl chloride (PVC), polyurethanes and plastics mean precautions may have to be taken for phosgene and hydrogen cyanide gas as well.

Suitable breathing equipment must be worn when it becomes necessary to enter heavy concentrations of poisonous or objectionable gases. The mine rescue person will constantly assess conditions based on chemical and physical facts. Such basic knowledge is very important in fighting mine fires.

Causes of fires

Most fires occurring underground are caused by the following:

- Electricity;
- Manmade (deliberate or accidental);
- Spontaneous combustion; and
- Friction.

Electricity

Some mine fires are caused by the use or misuse of electricity on battery locomotives, power cables, trolley wires, motors, electric heaters and even light bulbs. Worn insulation on live wires is a common source of fires in mobile equipment. Overloaded electrical circuits can cause electrical cables to overheat.

Circuit breakers or fuses provide protection against overloaded electrical circuits, but if someone tampers with fuses or circuit breakers, then this protection is lost and overheating can take place. Electrical circuit protection devices are fire prevention devices and tampering with one can cause electrical cables or motors to burst into flames.

Other common causes of mine fires are the over fusing and shorting out of deteriorating wiring on vehicle control panels and faulty battery cables.

Manmade (deliberate or accidental)

Welding and burning, and smoking and blasting operations are among the many causes of fires. Strict control and patrol procedures must be observed whenever welding is done in any place where the welder may bring the three sides of the fire triangle together.

A worker in a lunch room may throw a hot match or cigarette into the garbage can. A welder cutting steel in a shaft or a raise can provide a source of heat (hot metal or slag) that causes a fuel to ignite. Active burning can be delayed for long periods of time by a slow smouldering or oxidation of wood started by the hot slag. An active fire can break out many hours after the hot work is finished.

Accidental leakage of petroleum products on hot machinery is another common cause of fires. For example, the leakage of hydraulic fluids and diesel fuel onto hot engine exhaust manifolds causes a number of underground fires every year.

Spontaneous combustion

Spontaneous combustion occurs when ventilation is not sufficient to carry away the heat of oxidation. Slow oxidation of a pile of oily rags, old timber, etc. can generate enough heat to cause burning to start without any outside source of heat because the material is highly combustible. As oxidation starts, heat is produced which causes the oxidation to speed up which, in turn, creates more heat. This chain reaction eventually causes the material being oxidized to burst into flame.

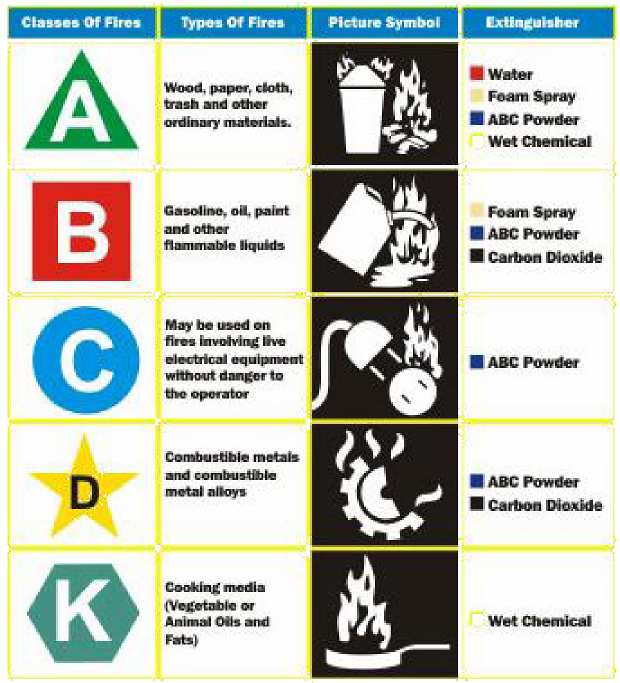
In 1972, a mine fire at the Sunshine mine in Idaho killed 91 underground workers. The origin of the fire is believed to be spontaneous combustion of timbers and refuse disposed of in an abandoned section of the mine.

Friction

Friction causes overheating of brake bands or clutches on slushers, transmission gear boxes and v-belt drives. Two of the most common friction-caused fires are the result of forgetting to release vehicle parking brakes and clutch slippage. Conveyor belts slipping, overheated bearings or rubbing against flammable items have also caused fires.

Classes of fires

Class A fires involve ordinary combustible materials, such as wood, cloth, paper, rubber and many plastics. They require the cooling effects of water or water solutions, or the coating effects of certain dry chemicals that slow down fire.



Classes Of Fires	Types Of Fires	Picture Symbol	Extinguisher
A	Wood, paper, cloth, trash and other ordinary materials.		Water Foam Spray ABC Powder Wet Chemical
B	Gasoline, oil, paint and other flammable liquids		Foam Spray ABC Powder Carbon Dioxide
C	May be used on fires involving live electrical equipment without danger to the operator		ABC Powder
D	Combustible metals and combustible metal alloys		ABC Powder Carbon Dioxide
K	Cooking media (Vegetable or Animal Oils and Fats)		Wet Chemical

Class B fires occur in the vapour-air mixture over the surface of flammable liquids such as greases, gasoline and lubricating oils. A smothering or combustion-inhibiting effect is necessary to extinguish Class B fires. A dry chemical, foam, vaporizing liquids, carbon dioxide and water fog can all be used as extinguishing agents, depending on the fire.

Class C fires involve live electrical equipment where safety to the operator of the extinguisher requires the use of electrically nonconductive extinguishing agents. Dry chemical and carbon dioxide are suitable. Because foam, water and water-type extinguishing agents conduct electricity, their use can kill or injure the person operating the extinguisher, and severely damage electrical equipment.

(Note: When electric power is disconnected, Class A or B extinguishers may be used.)

Class D fires involve certain combustible metals (such as magnesium, titanium, zirconium, sodium and potassium) and require a heat-absorbing extinguishing medium (dry powder) that will not react with the burning metals. Specialized techniques, extinguishing agents and extinguishing equipment have been developed to control and put out this type of fire. Normal extinguishers should not be used on metal fires because they may contain substances that will react chemically with the burning metal, and make the situation even worse.

Class K fires involve unsaturated cooking oils in well-insulated cooking appliances located in commercial kitchens.

Though such fires are technically a subclass of the flammable liquid/gas class, the special characteristics of these types of fires, namely the higher flash point, are considered important enough to recognize separately. Wet Chemical extinguishers can be used to extinguish such fires. Appropriate fire extinguishers may also have hoods over them that help extinguish the fire. Sometimes fire blankets are used to stop a fire in a kitchen or on a stove.

Stages of mine fires and control

Fires may start at any time. Fires are more quickly discovered and suppressed when they occur in an occupied area. If a fire breaks out in an enclosed space or empty building, 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 solutions, like changing ventilation procedures, if danger is to be reduced and further damage is to be prevented.

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 following phases of fire at any time. Knowledge of these phases is important for understanding ventilation and firefighting principles.

Stage 1: Incipient phase

In this first phase, the oxygen in the air has not been reduced significantly. The fire is producing 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 area may be only slightly increased, the fire may be producing a flame temperature in excess of 537^{o}C. Incipient fires generate heat, smoke and flame damage.

Control: In this stage, the fire is just getting started and can generally be extinguished on the spot with water or suitable extinguishers by the workers who discover it.

Stage 2: Free-burning phase (steady state burning phase)

During the second phase of burning, oxygen-rich air (+16.25 per cent oxygen) is drawn into the flame as convection carries the heat to the top of the enclosed area. From the top downward, the heated gases expand laterally, forcing the cooler air to lower levels and eventually igniting the combustible material in the upper levels of the area. The first indication of a fire may be the discovery of smoke in air currents at some distance away or even on surface.

Control: This is the time when breathing apparatus must be worn by persons trying to locate and put out a fire. One breath of this superheated air can sear the lungs. It may be possible to get within sight of such a fire from the fresh air side while staying in fresh air. This is often the case, and should always be carefully considered. Workers should never attempt to get to a fire against the smoke if it is possible to get to it in fresh, clean air. A fresh air route has two advantages: time and safety.

A fire may grow quickly and will often create its own convection currents that are strong enough to overcome strong drafts and back up smoke. Every attempt should be made to fight an underground fire by direct action, even if it will take many days.

Fire temperatures can exceed 700^{o}C. As the fire progresses through the latter stages of this phase, it continues to consume any free oxygen until there is not enough oxygen to react with the fuel. The fire is then reduced to the smouldering phase.

Stage 3: Too hot to proceed phase

In the third phase, there may be no detectable flame if the area is sufficiently airtight. Burning is reduced to glowing embers. The area becomes completely filled with dense smoke and gas. Smoke and gas may be forced by pressure through any openings and cracks. The fire will continue to smolder at a temperature well over 537°C. Such conditions could make it impossible to get directly at a fire in a stope, underground hoist room, chute, manway, sublevel, mining room, etc.

Control: If direct methods fail, the next step is to erect fire seals in a reasonably safe and comfortable location to seal off the area involved on both the level above and below, or even on the same drift as the fire. Once sealed, the mine rescue team must follow proper procedures before opening seals, and they must be aware of the potential for back draft.

Stage 4: Out of control phase

It is not always possible to control a mine fire by conventional methods. This condition is called the fourth stage. A fire in this stage can only be controlled by sealing it off on the surface. Control: This is a long drawn-out process, as every surface opening may have to be sealed, plugged or covered with solid bulkheads, concrete or tonnes of fill.

Carbon monoxide may build to explosive proportions when combined with mine gases and cause severe damage to the bulkhead seals. Large quantities of dry ice could be dumped down the openings, or the fire area flooded with inert gases, such as carbon dioxide and nitrogen. Flooding of a mine with water is the very last resort. It is used only when every other method has failed. Although Saskatchewan has no underground coal mines, there are coal mines in Canada and North America that have been sealed after stage four fires.

Thermal Layering of Gases

This is the tendency of gases to form into layers according to temperature. Other terms for this are heat stratification and thermal balance. The hottest gases tend to be in the top layer, while the cooler gases form the lower layers.

Thermal layering is critical to firefighting. As long as the hottest air and gases are allowed to rise, the lower levels will be safer for firefighters

The thermal layering process can be disrupted if water is applied directly into the hottest layer. When water is applied to the upper level of the layer, the rapid conversion to steam can cause the gases to mix rapidly. When water is converted to steam it expands 1,700 times, which can have a disastrous effect on a fire scene if not handled properly, and prepared for.

This causes hot gases to mix throughout the fire area and is referred to as disrupting the thermal balance or creating a thermal imbalance. Many firefighters have been burned when thermal layering was disrupted.

Even surface firefighters train to understand that the proper procedure is to ventilate and direct the fire stream at the base of the fire so as not to disrupt the thermal balance. Because this is not often practical underground, the possibility of steam burns to rescuers MUST be considered and reflected in the team training if water is chosen as a preferred method in underground firefighting.

Water is however useful when kept at a wide fog to protect the team members from heat while working near, or advancing towards the fire scene. This of course has to be done with cautious consideration to the effects of the heat on the back. Never allow a team to advance into the fire area without checking the back.

Fire extinguishing and control methods

Extinguishing agents

Fire extinguishers provide excellent protection against a minor fire becoming a raging inferno when suitably applied to the hazards for which they are intended.

The four basic classes of fires require slightly different extinguishing methods for safe and effective control.

Water type extinguisher

This is a Class A type fire extinguisher. The method of controlling is by cooling the fire with a quenching agent which in this case is water. The water is applied to the fire with:

- A hand operated pump tank;
- A pressurized tank with a release valve mechanism;
- A tank pressurized with a high pressure cartridge;
- Water lines; and
- Mobile water trucks, tanks, etc.

Water type extinguishers are effective and safe on Class A fires only. They must not be used on Class C and D fires.

Carbon dioxide extinguisher:

These are safe to use for Class A, B, and C fires, but only recommended for Class B and C fires because they are only moderately effective on Class A fires. The extinguishing agent is liquid carbon dioxide while in the extinguisher, but is discharged as a snow that vaporizes quickly to carbon dioxide gas and extinguishes fires mainly by excluding or diluting oxygen.

Important: Caution must be exercised in using this smothering type of fire extinguisher in an enclosed area. It is designed to prevent oxygen from reaching the fire and it can, of course, prevent oxygen from reaching the firefighter as well. Often, a “frost” residue will form on the nozzle horn. Contact with the skin could result in frost bite.

Dry-chemical extinguisher:

Dry chemical extinguishers are among the most common portable fire extinguishers used today. There are two basic types of dry chemical extinguishers:

- Ordinary dry-chemical extinguishers rated for Class B and Class C fires; and
- Multipurpose dry-chemical extinguishers rated for Class A, B and C fires.

The following dry chemicals are commonly used in ordinary base and multipurpose agent fire extinguishers:

Ordinary Base:

- Sodium bicarbonate;
- Potassium bicarbonate; and
- Potassium chloride.

Multipurpose Agent:

- Monoammonium phosphate;
- Barium sulfate; and
- Ammonium phosphate.

These chemicals are mixed with small amounts of additives to prevent the agent from caking and to allow it to be discharged easily. Care should be taken to avoid mixing or contaminating ordinary agents with multipurpose agents and vice versa. Like the carbon dioxide extinguisher, dry chemical extinguishers are safe on Class A, B, and C fires and are highly recommended for Class B and C fires. The extinguishing agent is usually sodium bicarbonate or potassium bicarbonate in dry powder form that has an added component to repel moisture and maintain free-flow. The powder is expelled under pressure produced by puncturing a small carbon dioxide cartridge attached to, or confined within, the extinguisher or just by pressurizing with injected nitrogen.

As the ejected powder granules are warmed by the heat of the fire, each granule produces carbon dioxide gas, which excludes or reduces oxygen in or near the fire or by chemical flame inhibition.

High-expansion foam:

This foam is created by spraying a mixture of concentrated detergent and water through a knitted nylon netting, causing bubbles to form. Enough bubbles are generated to form a “foam plug”. The velocity of air forces a steady stream of foam (i.e. the plug) with a continuous volume against the fire. Once the foam reaches the fire, it continues to displace fresh air and hold the steam and oxygen deficient atmosphere around the fire. The resulting steam-air mixture has an oxygen content that does not support combustion, so cooling and extinguishing occurs. Foam wets all objects that it contacts, thus making it useful only in fighting Class A and B fires.

Water fog:

This is a modern firefighting device, useful and safe for Class A and B fires both on the surface and underground. A water fog is made up of millions of fine particles of water sprayed through a special high-pressure nozzle. As the super-fine spray hits the fire, the heat is reduced from as much as 982^{o}C to 93^{o}C and the water is turned into steam. This cuts off the oxygen and extinguishes the fire. A water fog produced by a proper “impinging type” nozzle is very useful as a heat barrier for rescue teams advancing towards a Class A fire.

Halon (1301 AND 1211)

Halon is an electrically non-conductive gas, is an effective medium for extinguishing a fire. It extinguishes fires by inhibiting the chemical reaction of fuel and oxygen. The extinguishing effect due to cooling, or dilution of oxygen or fuel vapor concentration, is minor. Fire extinguishing systems, either total flooding systems or local applicators, are useful in extinguishing fires where an electrically nonconductive medium is essential or where cleanup of other types of extinguishing media presents a problem. It has not been found effective on combustible metal fires such as in Class D fires.

Potash or rock dust

Fine potash, limestone or shale dust can be used successfully in fighting fires in the early stages and for larger fires under some conditions. It serves to exclude oxygen from the heated area and may also reduce the heat of the burning material. Small fires may be controlled by potash dust applied by hand shovels. Fine sand and backfill can also be used in making a direct attack. Sand, however, is heavier than potash dust and, therefore, more difficult to handle. Covering burning material with rock dust does not produce fumes as does the use of chemicals, nor does it product steam and hydrogen as does the use of water. It can also be used on all classes of fires

Dry powder for class D fires:

The agent used in most dry powder extinguishers is sodium chloride. Flow enhancers and a thermoplastic material are added to the sodium chloride to enhance crusting after the material is discharged onto the metal fire. Refer to the manufacturer’s recommendations for use and special techniques for extinguishing fires in various combustible metals.

Sealing of a mine fire

The purpose of sealing in a mine fire is to cut off the oxygen supply and help prevent contamination from smoke and gases entering other areas of the mine. A mine fire might also be sealed because:

- If the fire cannot be fought by direct means of extinguishment; and
- The location of the fire is in a stope, chute, manway, mining room, etc.

It is best if seals can be constructed on the INTAKE and EXHAUST sides simultaneously. If this is not possible, the seal on the FRESH AIR side should be erected first.

If it becomes necessary to seal the EXHAUST side first, consideration should be kept in mind that the rescue team will be endangered by the extremely toxic and hot atmosphere, and being faced with danger of an explosion caused by the backing up of explosive gases over the seat of the fire.

A short pipe or tubing built into the stoppings can be used for a vent and for inserting probes to check the gases and temperature in the fire area. After sealing is complete, all non-mine rescue personnel must immediately leave the fire area until it is safe to return. If workers have been trapped in the mine, mine rescue teams must concentrate on rescuing them as soon as it is safe to do so.

Temporary stoppings or seals

Temporary stoppings or seals can be built very quickly in an emergency. They can be constructed with brattice that is fastened to walls, backs, floors or wooden frames. Non-sparking tools should always be used in an explosive atmosphere. Stoppings should be set at an adequate distance in the opening and as close to the fire as safety permits. Allow enough room for a secondary seal. All ground in the vicinity of the stopping must be well checked and scaled down.

Important: Special attention must be given to backs (roof) because experience has shown that heat will deteriorate backs in some types of ground. Temporary stoppings should be of sufficient strength to provide a tight seal.

Unsealing

No attempts should be made to unseal a mine fire until the:

- Oxygen content of the sealed atmosphere is low enough to eliminate the possibility of explosions;
- Carbon monoxide (indicator of combustion) has been reduced to a safe level; and
- The temperature has cooled down well below the point of ignition.

Gas tests of the atmosphere behind the stoppings should be taken at reasonable intervals as determined by the Director of Rescue Operations. Gas tests should be taken through the seal with as little disturbance as possible to the seal. Disturbance of the seal, even for a short period of time before determining the fire is out can introduce a fresh supply of oxygen resulting in a very hazardous situation. Mine rescue teams testing gas levels must wear self-contained breathing apparatuses.

Method of unsealing

Once the conditions listed above are met, the rescue team, wearing self-contained breathing apparatuses and carrying extinguishers, may proceed to the sealed fire and:

- Erect an air-lock on the fresh air side of the seal;
- Carefully open the temporary fire seal;
- Check the fire area thoroughly for bad backs and sidewalls (expect poor roof conditions).
- Note the temperature in the sealed area;
- Reseal fire if conditions indicate the fire is not out;
- Repeat the above steps at reasonable intervals;
- If temperature, oxygen and carbon monoxide levels are within safe limits, open barricades or stoppings and restore ventilation;
- Maintain constant patrols until conditions return to normal (any increase in carbon monoxide is cause for alarm); and
- Once ventilation is restored and the air is within the regulated limits, open or barefaced miners can begin recovery and preparation of mining operations.

Permanent stoppings

These are done by erecting permanent barricades or stoppings. These must be constructed in accordance with any mine regulations and require the permission of the Chief Mines Inspector.

They can be built of timber, concrete, cinder blocks, bricks, back fill or other suitable material.

Summary

In summary, if any fire is found in a mine, prompt action must be taken. Safety always comes first.

If your site has specific procedures for workers to follow when encountering a mine fire then those are the procedures that should be followed. During an emergency situation it is vital that all involved go where, and do what they have been instructed to do.

If an incipient or small fire is found, action must be taken immediately to contain or put it out. Use water and Class A extinguishers on Class A fires. Use a smothering approach for Class B and C fires. Use only "dry powder" extinguishers for Class D fires. Electricity must always be turned off in electrical fires. No attempt should ever be made to extinguish electrical fires with water.
Approach a fire from the upwind side, and be careful in enclosed areas when using smothering type fire extinguishers.

If, after a few moments, definite progress is not made or it becomes apparent the fire cannot be contained: Sound the alarm! Warn workers! Initiate evacuation!

Remember that fires constantly produce deadly gases. Workers must not be exposed to these gases or other hazards associated with fires, such as explosions, weakening timber or deteriorating ground. Every fire, regardless of how small, must be reported at once because it may have released deadly gases into the mine's air. Once put out, the fire area must be monitored until re-ignition is impossible.
After a fire extinguisher is used, it must always be returned for recharging and its use recorded.
Any unusual occurrences in the mine should be noted and reported at once. An unusual occurrence could be:

- The odours of smoke or other contaminants;
- Clouds of dust;
- Blasts of air, caused by a fall of ground or inrush of water;
- Sudden changes in ventilation;
- Interruption of normal services such as power failures; and
- Unusual noises or explosions.

Any of these signs could mean that something irregular or dangerous has happened that the life of the workers could be endangered and quick action might have to be taken.

Chapter Five - Mine Rescue Procedures

Mine Rescue team objective

Most people associate "mine rescue" with saving lives. Although saving lives is the most important part of mine rescue work, there is more work involved. A more complete definition of mine rescue is:
"the practiced response to a mine emergency situation that endangers life, property, and the continued operation of the mine."

Mine Rescue principles

Mine rescue and recovery work involves a wide variety of tasks. Four fundamental principles exist for an effective mine rescue operation. These principles, in order of importance, are:

1. Ensure the safety of the mine rescue team.
2. Make every effort to rescue or secure the safety of trapped workers.
3. Protect mine property from further damage caused by fire, cave-in, etc.
4. Return the mine to a safe condition so operations can resume.

Competent persons appointed

Each mine must appoint a certified person who is responsible for training mine rescue personnel and supervises the maintenance of the rescue equipment. The site must also appoint a person to act as a coordinator or briefing officer. The employer must have all breathing, resuscitating, testing apparatus and rescue equipment examined on a monthly basis and properly maintained.

All mine refuge stations must be inspected as well and the record of this examination must be reported in writing to the employer who will have it countersigned. All rescue equipment must be maintained in a state of readiness for an emergency. Any supply shortages must be replaced.

Inspectors from Mine Safety Unit of Saskatchewan may inspect the breathing apparatus and any other mine rescue equipment to make sure that the mine is properly equipped. As well, the inspectors may examine mine rescue training records to ensure personnel have the training to carry out a mine rescue and recovery operation.

Mine Rescue duties

Operating on the basis of the four fundamental principles, some of the duties a team may have during an actual emergency are:

- Determining gas conditions and ventilation flows;
- Mapping the team's findings;
- Searching for and rescuing survivors;
- Performing first aid;
- Resuscitating victims;
- Administering oxygen;
- Exploring the affected area of the mine;
- Determining the extent of the damage;
- Locating and fighting fires;

- Building temporary and/or permanent stoppings;
- Erecting seals in a fire area;
- Clearing debris, pumping water and installing temporary roof supports;
- Moving equipment;
- Extricating casualties; and
- Restoring ventilation by restoring power and moving fans, etc.

Careful consideration must be given to:

- The method and the extent of work a team is expected to perform;
- How the team wearing breathing apparatuses can best be utilized;
- Weighing the benefits of the operation against the hazards the team will encounter;
- The best way to perform the work safely; and
- What offers the best chance of saving trapped workers.

The Chief Mine Inspector, through the Provincial Mine Rescue Coordinator, has control over the certification program to ensure the site instructors are delivering adequate training. They also monitor the quantity and nature of equipment to ensure the equipment meets required certifications.

During a mine emergency, the general manager of the operation has the responsibility of ensuring an effective response to the emergency. This may involve personally directing the activities of the emergency response or delegating it to someone under his direction that may have more experience or expertise. The responsibility will still lie with the general manager.
The chief mine inspector through officers of the Mine Safety Unit and the Provincial Mine Rescue Coordinator, works with the companies to ensure compliance with mine regulation. The mine safety unit does not direct the response to any given emergency.

Senior management

Senior management is responsible for:

- Having the required number of mine rescue team members trained and available;
- Providing the required equipment; and
- Having an emergency plan.

Director of Rescue Operations

A mine's Director of Rescue Operations has a very important function, must be a senior company official, and must also know mine emergency and emergency response procedures. He must also be thoroughly familiar with, or have the appropriate resources available for:

- Mine and mining methods being used in that mine;
- Equipment used in normal day-to-day operations and its location;
- Supply of power the equipment uses;
- Ventilation system;
- Amount and direction of airflow;
- Location and capacity of fans;
- Location of electrical power lines and switches for the fans;
- Location of ventilation doors and brattice stoppings;
- Location of telephones and other communication equipment;

- Location and availability of firefighting equipment, storage depots for brattice, and other material and equipment required to build fire seals, control fires, and change or restore ventilation;
- Location of facilities such as refuge stations, vehicles, and any other emergency equipment that may be used in recovery operations;
- Location of possible hazardous areas such as fuel and oil storage areas, timber, bad ground conditions, water problems, and gaseous situations;
- Functions and limitations of the breathing apparatus used by the team;
- Capabilities of the team, and the atmospheric testing equipment used by them;
- Emergency first aid equipment, material, and its location;
- Latest large scale mine plan and all pertinent information that is relevant to the problem areas; and
- All important information, messages, and directions should be logged.

Since the Mine Rescue Team, the Coordinator, the Director of Rescue Operations and his assistants are required to work cooperatively, careful consideration and planning are essential.

When making decisions and plans, the Director of Rescue Operations should consider:

- The details and facts provided by persons involved in the incident;
- Probable conditions in the part of the mine to be explored as known from information already received;
- The route of travel, visibility, and familiarity with the location;
- The number of competent rescuers available, and the limitations of both them and their equipment;
- The vehicles available to speed up the operations, and the possible hazards that may result from their use;
- The distances to be traveled and the limitations of the apparatus in the event of vehicle failure on the journey in or out of an emergency area;
- Communications between the rescue team and the coordinating centre;
- The availability of emergency equipment and material stored underground that could be used by the rescue team;
- The potential hazards the team may encounter such as cave-ins, water, gases, etc.;
- Anything to make sure no work done will endanger the team and trapped workers; and
- The assistance and material that could be made available from neighbouring mines and suppliers.

- All important information, messages and directions should be logged.

Mine Rescue Coordinator duties

The Mine Rescue Coordinator, otherwise known as the Briefing Officer or Fresh Air Base Coordinator will be stationed at the fresh air base and should have extensive mine rescue training, good leadership skills and be knowledgeable in the workings of the mine. The coordinators key function is to not only act as a communication link between the director of operations and the team but to act also as a cautionary link. The coordinator must ensure that whatever directives are passed to the teams are within good mine rescue principles.

The Coordinator reports directly to the Director of Rescue Operations and acts on his orders or advice. He should also be in a position to inform the Team Captain of all relevant data and give instructions on the work to be done. The progress and actions of the team should be accurately marked on the mine plan and all relevant details logged.

Because the Coordinator's job is so important, it is essential that everyone at the fresh air base respect the Coordinator's authority and do whatever they can to help. In order to make the job easier, only those people necessary for the operation should be allowed at the fresh air base.

The main responsibilities of the Coordinator are:

- Maintaining communications with the rescue team and the control centre;
- Following the team's progress on the mine plan and recording the findings as the team reports;
- Coordinating and overseeing the activities of all personnel who are at the fresh air base; and
- Ensuring that the team is properly checked out, equipped and well briefed before leaving the base.

Team Captain

One member of the mine rescue team is designated the Team Captain. The Team Captain leads the way when a team is advancing on foot. The most important quality of a mine rescue Team Captain is leadership. An important part of this leadership is instilling confidence in the team members and ensuring that they follow the training they were given.

The Team Captain leads and directs the team members and is responsible for discipline, general safety and the work they perform The Team Captain should not take part in any work other than that directly involving the safety of the team. This allows the captain to oversee activities and be alert to hazards.

The Team Captain reports to the Mine Rescue Coordinator and is under his direction. However, when the team is on a mission, the Captain is its chief decision maker. It is vital for the Captain to be knowledgeable in all facets of mine rescue theory and procedures so that they can make correct and timely decisions as circumstances dictate.

The Team Captain will probably have some team members with more detailed knowledge of certain subjects, but it is up to the Captain to utilize to their best advantage, the team's skills and resources on the rescue operation.

Vice-Captain

The Vice-Captain on a rescue team follows at the rear of the team when it is advancing on foot. In the event the Captain is unable to continue, the Vice-Captain takes control of the team. The Vice-Captain must, therefore, have similar qualifications to that of the Captain.

One of the Vice-Captain's main duties while travelling is to keep watch on all members of the team and to warn the Captain should any team member show signs of distress. The Vice-Captain acts as a second pair of eyes for the Captain and, in addition to observing the team members, keeps a sharp lookout for any condition missed by the Captain.

The actual distribution of jobs among team members may vary from team to team. However, it is common practice to have the Vice-Captain assist the Captain in updating the mine plan and taking gas and ventilation tests. The Vice-Captain also makes close checks of team members during rest breaks and assists the Captain with routine duties. The Vice-Captain must be kept informed of the Captain's findings, the work done and the work still to do.

Rescue Team Member

Various other duties, such as first aid and firefighting, are distributed among the other team members. When vehicles are used, a driver will be designated. Generally, it is desirable to have all team members well trained in the common types of work that teams do, such as first aid, firefighting, air sampling, and installing seals.

As mine rescue teams are assembled, consideration must be given to the special skills that may be required. Team members should be chosen with these factors in mind. Emergencies in mines require the special skills of mine rescue workers.

Training

Only through regular practice will individuals learn to work effectively on a team and develop confidence in their mine rescue skills.

In mine rescue work, the life of every team member depends on the actions of the other team members. If members of a mine rescue team do not work effectively as a team, then their lives are in danger. The importance of cooperation cannot be overemphasized.
The first consideration of any mine rescue operation is the safety of the individual team members.

Without the team, there will be no rescue and no recovery.

To be considered an active member of a Mine Rescue team each member must participate in at least 40 hours of mine rescue training. The training should consist of breathing apparatus, firefighting, ventilation, gas testing, rescue and all extrication tools used by the site.

The teams must be familiar with the procedures necessary to initiate a timely response to an emergency including gathering tools and equipment, bench testing and all fresh air base procedures so that by the time a directive is ready for the team they are ready to go.

Most mines rely on mutual aid to respond to an underground emergency and cross training with the mutual aid partners will only increase the ability to respond efficiently with a mixed team, specifically if different types of apparatus are being benched at the same time.

Control or Command Centre

A rescue headquarters should be established to direct the rescue and recovery operation. This headquarters is called the Control or Command Centre and houses the Director of Rescue Operations and his advisors.

A good communications system is essential for the effective operation of the Command Centre. This centre should be linked with the fresh air base at all times and must have access to a switchboard so that staff can talk with various personnel at the mine site and points outside. The Control Centre must have:

- An up-to-date copy of the contingency plans for the mine;
- Updated mine and ventilation plans;
- The names and phone numbers of personnel that may be involved in a rescue and recovery operation;

- Any other information that may be of assistance in planning and carrying out the rescue operation; and
- A directory of resources.

Mine Rescue stations

At each mine, a competent, certified person shall be appointed to supervise rescue teams in all rescue work and operations at the mine.

Each underground mine is required to install, equip, operate and maintain a mine rescue station. The station must be equipped with the following items:

- Effective means of communication to the underground portions of the mine;
- Effective portable lights;
- Adequate first aid equipment;
- Gas detecting instruments and their accessories;
- Basic rescue equipment including an axe, sledge-hammer, claw hammer, pick, shovel, saw and scaling bars;
- Adequate supplies of primary four hour self-contained breathing apparatus and testing equipment;
- Adequate repair parts for the respiratory protective devices;
- Enough oxygen and carbon dioxide absorbent to allow at least five trips into the mine by the teams;
- Emergency lighting;
- A smoke or fire detector that sounds an alarm at a central surface location;
- Adequate supplies of secondary self-contained breathing apparatus for rescue; and
- Firefighting equipment must also be immediately available.

The Fresh Air Base

The fresh air base is the base of operations from which rescue and recovery work advances into irrespirable atmospheres.

It functions as a base of communication for the rescue operation, linking the team, the control centre and support personnel. The Fresh Air Base Coordinator and assistants are stationed at the fresh air base as well as where the rescue crews begin their operations into the affected areas.

The base may be on surface or underground, as conditions require, but should be as near the emergency scene as possible. Depending on the mine site's procedures, the fresh air base may be moved underground due to the amount of travel required and the ability to do it under oxygen in a four hour apparatus.

The essentials of a fresh air base should include the following:

- An assured supply of fresh air;
- An assured travel way in fresh air for workers and material travelling to the surface;
- Communications with the control centre and with the Captain of the team on the mission;
- The best illumination possible;
- Sufficient room to permit work without confusion;
- First aid supplies;
- Necessary tools and equipment; and
- Oxygen and carbon dioxide absorbent.

Basic tools/equipment/personnel

Team members should be equipped with:

- Fire retardant and highly reflective clothing;
- Approved industrial protective headwear with a retention system; and
- CSA approved steel toed, steel shanked, oil, acid, and water resistant work boots.

Communication between the fresh air base and the team

It is important that the mine rescue team stay in close contact with the fresh air base to report the team's progress and to receive further instructions.

It is also essential that communication be established between teams working ahead of the fresh air base and the base itself. When wearing breathing apparatus, communication may be carried on by telephone, two-way radio or other suitable means. A microphone on the face piece can help boost the sound to provide effective communication over the phone.

A wired telephone system is another method of communicating with the fresh air base. One team member wears the equipment and is responsible for staying in contact with the base while another is in charge of winding and unwinding the telephone line. This method is suitable only when the exploration involves short distances.

As technology advances there are more options becoming available for continuous communications such as tablets that allow Captain and Coordinators to be up to date at all times with team travel.

There is less anxiety and a more efficient overall rescue operation if the Captain reports to the fresh air base at every convenient opportunity. This also enables the Director of Operations to follow the progress of the team and plot it on the mine plan.

A speaker phone works well at the fresh air base because it permits all concerned personnel at the base to listen in on the two-way conversation. Two-way radios can be used if the proper aerial system is in place underground.

Standard code of signals (horn, whistle, or similar)

The standard code of signals for mine rescue teams adopted in Saskatchewan, other provinces and the United States is:

One: Stop
Two: Advance (move toward the Captain)
Three: Retreat (move toward the last person in order of travel)
Four: Distress or Emergency

Both the Team Captain and the Vice-Captain do the signaling. It is standard practice for each to return or acknowledge the other's signal before anyone on the team moves.

These basic signals are normally used in conjunction with various hand or Captains stick signals given by the Captain. Hand signals are not standardized, but are worked out by each team to best suit their operating techniques. It should be remembered that no matter what method of signaling a team chooses, it will likely not be suitable for all occasions, as a signal by sight will not be visible in smoke nor a horn or voice be audible in noisy areas.

The team rest periods may be indicated by hand or sounding stick motions or just verbally. Since all modern face masks are equipped with speaking diaphragms, voice communication is becoming more acceptable in mine rescue work than it was in the past when mouth pieces were prevalent.

Team members must know the Captain's signals so that instructions can be followed without hesitation. Strict discipline must always be maintained and all team members must obey, without question, all directions and signals given by the Captain. There will be times that a Captain will rely heavily on a team member that has more expertise in an area but overall the Captains authority is not to be questioned. During periods of inactivity the team must not wander about needlessly while the captain is updating the maps or discussing action plans with the coordinator.

Progress reporting and mapping (record keeping)

Information the rescue team relays to the fresh air base is known as the "progress report." Progress reports keep the fresh air base and control centre up-to-date on what the team is doing, where it is and what it has found. This information is used as a basis for making further rescue and recovery plans.

These reports not only inform the fresh air base and control centre on the whereabouts and conditions of the team, but also provide information on the conditions found in the mine. These reports, as they are phoned up from the mine, confirm or disprove the suspected problems and conditions. Whenever the Captain reports anything, it is important to log the location and time that the information was obtained.

As the team advances through the mine, all events and conditions encountered are marked on the Captain's mine plan. When the Captain makes his progress report to the fresh air base, this information is recorded on the mine plan on the surface. This mapping provides the fresh air base and command centre with a visual record of what is happening underground.

Team preparation before going underground

Briefing the team - directives

Team members must be fully briefed on mine conditions and the work expected of them before the team leaves the fresh air base. The team briefing should only take place after all decisions about the operation have been made. This prevents argument about the proper steps to be taken once the briefing has begun. If possible, the briefing should take place in a quiet room where questions may be answered and the work expected of the team thoroughly explained without confusion. The Captain only takes orders from the Coordinator. All pertinent instructions should be issued in writing and the captain should summarize the directives back to the Coordinator to ensure they both understand the directives clearly.

During the briefing, the team must be given all relevant information available. The team should answer the following questions before beginning exploration:

- Is the evacuation complete?
- Are any workers missing? Where is their likely location?
- Has the down board been checked and secured?
- What is known about the cause of the disaster?

- Is this team the first team in the mine? Are other teams in the mine?
- Are guards stationed at all mine entrances?
- What is the team's mode of travel?
- What is the extent of the exploration and work performed by previous teams?
- Is the ventilation system operating?
- Will the team's travel be in the intake or exhaust? What are the gas concentrations and the amount of airflow?
- What is the team's objective?
- What is the team's time limit for the operation?
- What conditions are known to exist underground?
- Is the mine communication system operating?
- Is the power to the affected area on or off?
- What is the condition of the air and water lines?
- Are there diesel or battery-powered equipment or charging stations in the affected area?
- What equipment is needed or available? Where is it located?
- What type of firefighting equipment is in the mine? Where is it located?
- What tools, rescue equipment, and supplies are available underground? What is their location?
- Are there storage areas of oil, fuel, oxygen, acetylene or explosives in the areas to be explored?
- Are there any other conditions or equipment that the team should be made aware of?

All important information should be marked on an updated mine plan and given to the Captain. The communication points or telephones that the Captain will use to make his reports to the fresh air base should also be agreed upon and marked on the mine plan.

Familiarization with mine workings

In a major fire, it may be necessary to bring in rescue teams who are not familiar with the mine workings. Each team must include more than one member familiar with the mine to guide the team.

Check and guard mine openings

The mine's exhaust air should be checked for gases. The shafts should be guarded so no unauthorized persons enter the area. Care must be taken that no one is exposed to toxic gases that may be discharging from the shafts.

Before going underground

Before going underground, the Coordinator must be certain the Team Captain has:

- Confirmed all members of the team have been deemed fit by a physician to undertake the job;
- Field tested all primary, secondary and back-up breathing apparatus to ensure air tightness and proper functioning of the working parts;
- Had each team member complete the bench or field tests on the apparatus and any self- rescuers he may need to wear;
- Checked (or had team members check) the gas detectors, signal whistles, communication devices, link lines, cap lamps and any other equipment or tools that the team will take;
- Discussed the instructions with the team to make sure each member understands them and what he is expected to do;
- Noted the time the team has been given for the trip and synchronized watches with the Coordinator; the time limit of the trip must be understood by all;

- Checked that the required tools and materials are on hand;
- made sure a mine map, notebook, pencil, chalk and paint are available to take underground;
- The team put on the apparatus and "get under oxygen" when ready to proceed; and
- The Captain inspects team members' equipment:
  - headstraps and buckles;
  - facepiece (straight, no kinks in tubes, tight seal);
  - gauge reading (record pressures); and
  - overall condition of team member and apparatus (by sign or verbally).

The Vice-Captain makes a similar check of the Captain's apparatus and ensures the Captain has all his equipment. The Vice-Captain:

- Checks signal horns and communicating equipment;
- Carries apparatus tools;
- Reports to official in charge; and
- Notes time of departure.

Important: Before re-entering, the Mine Rescue Team members must be examined by a physician, or in the absence of a physician, the most competent medical person available under the direction of a physician.

Number of persons required for mine rescue and recovery work

Oxygen breathing apparatus should be used only when there are enough trained people available to form a five-person team to carry out the operation. Teams of fewer than five members are only allowed with permission from the Chief Mine Inspector or his designate, the Mine Rescue Coordinator.

This request would typically be made for using smaller teams to travel the mine verifying the mine air is safe to allow workers to leave refuge stations after a mine fire has been controlled.

The deployment of the first team is dictated by the urgency of the situation during the early stages of an emergency. However, a second team must be preparing for back-up before the first team can proceed.

Generally, teams at the fresh air base should be organized in the following manner:

1. First team: on a mission in the mine.
2. Second team: at the fresh air base in a state of readiness as a "back-up" team.
3. Third team: on standby in support of the first and second teams until they are needed as a back-up team.

Fifteen trained people are needed to begin the team organization at the Mine Rescue Station. They are organized as follows:

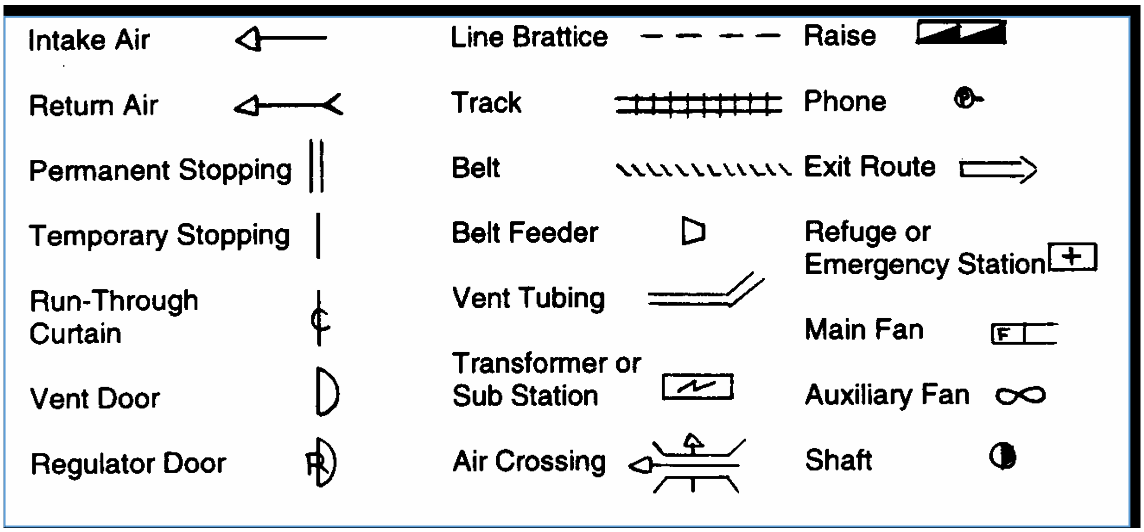
- Five people constitute a standard mine rescue team for work in unbreathable atmospheres;
- Five people in apparatus, but not under oxygen, remain at the fresh air base as a "back-up" team; and
- Five people acting as a standby or reserve team; they may work as assistants at the fresh air base until activated as the "back-up" team.

Important: The Mine Rescue Coordinator is not considered a mine rescue team member.

Note: If space permits and there is enough testing equipment, the "back-up" team should field test their breathing apparatus and equipment at the same time as the first team so they are ready for immediate "back-up" if needed.

The safety of the team always remains the main priority.

Suggested legend for mine plan



Time limits for rescue trips

A team should ordinarily allow twice the amount of time for the return trip it plans to use on the in-going trip. Only one-third of the oxygen in the apparatus cylinder worn by any member of the team should be used on the in-going trip. Two-thirds must be left for the return trip to the fresh air base. An exception to this procedure may be made where exploration or gas testing has been done on the way to the objective. The time or oxygen spent on these side trips need not be duplicated in estimating the amount required for the return trip.

The Captain should record the time of departure before the team leaves the fresh air base. It should be made clear that, if the team fails to return to the fresh air base, or fails to make contact as scheduled, the back-up team will be sent to search for them. All instructions about time limits must be obeyed.

Duration of rescue operations in high temperatures

Experience shows that mine rescue teams have less endurance in hot and humid conditions. A four hour team rotation in high heat and humidity may be impossible. In that case, additional teams will be required to make up for the shorter work period.

After being exposed to extreme temperatures and humidity for even a very short time, the team should rest for at least four hours.

In temperatures of approximately 45°C dry bulb reading and 38°C wet bulb reading, the amount of time team members spend under oxygen may have to be reduced to 20 minutes or less because of heat exhaustion.

Procedures while underground

Every task or exploration is different. Each one involves unknown factors and presents its own problems. It is difficult to predict precisely what a team may be required to do. Some accepted procedures developed over the years have become standard practice for teams during exploration. They are used as "guidelines" rather than "rules" because no procedure fits every situation.

Team/equipment checks

Team checks should be done as soon as practicable after the team leaves the fresh air base, when it enters into a bad atmosphere and at regular intervals of 15 to 20 minutes. These checks help make sure:

- Each team member is fit and ready to continue;
- Each team member's apparatus is functioning properly; and
- Each team has enough rest.

Usually the Captain or Vice-Captain checks the team by halting the team briefly and asking each team member how they feel. The Captain or Vice-Captain also records the time of the check and the cylinder pressures.

Discipline

Excessive talking should be discouraged. All team members must concentrate on the job at hand.

Team safety

The safety of the team is of utmost importance. It is the first principle of mine rescue. The Captain's top priority is always team safety. Teams entering a mine in an emergency are taking a calculated risk. Captains must give each situation careful thought before proceeding. Team safety comes first! The Captain should lead his team through the mine cautiously. They should pay very close attention to the roof and sides and to the condition of the mine atmosphere.

The team must be rested regularly and members constantly checked for signs of distress. All work must be assigned as evenly as possible so that no team member becomes too tired. Excessive rushing or running tires the team unnecessarily and, in some circumstances, may endanger lives.

Route of travel

The rescue team should explore a mine via the fresh air route whenever possible. There are two good reasons for this practice:

1. The danger to the exploring team is less; and
2. The fresh air base can be located closer to the emergency.

Circumstances may make it impossible to travel by a fresh air route. The Team Captain must always be sure the team has a safe route of retreat. If travelling underground via the exhaust shaft, ensure the hoistman is equipped with, and trained in the use of, breathing apparatus where necessary.

A rescue team should always properly mark the route it uses going in so that:

- The team can retrace its travel route without getting lost on the way out of the mine if working in poor visibility or in complicated mine workings; and
- If the team gets into trouble and cannot get out of the mine, the back-up team coming to its rescue can find it by following the marked route.

The route should be clearly marked by whatever method the rescue operation chooses. Options can include glow sticks, LED lights, hot packs (when using TIC camera), physical barricades or ropes, trailing communications lines or ropes, or a simple paint or chalk mark on the wall.

Whatever method is used it needs to be clearly understood by the teams, including any members of a mutual aid team.

As the site management team develops the guidelines for marking route of travel it is not uncommon to include provisions to not mark every intersection while in good air as long as the next pre-arranged communication point can be reached by following the agreed upon route. Any variance to the plan would require a team to begin marking the route.

Short stub intersections need not be marked with route markers if the face of the stub has been explored, dated and initialed by the Captain. All places of the team's retreat should also be marked, dated and initialed. This could be the end of the entry, cave, seal, door, or just the team's turn around in a long entry.

If the team retraces its steps, route markers should be canceled. The details and method of route markings must be understood by all back-up teams.

The team Captain must keep care and control of all members at all times. If conditions do not allow for visual contact due to poor visibility, the members must keep in physical contact by using life lines, holding hands, carrying a stretcher, etc.

This sometimes is not possible in smaller northern mines because cages are not big enough for a whole team. Extreme caution must be used when travelling under conditions of poor visibility.
When any work is being done by the team (e.g., building stoppings, timbering, scaling, etc.), the Captain or Vice-Captain must always be on guard against hazards or risks to the team's health and safety.

Order of travel

The Captain always takes the lead as the team advances. It is standard practice for the Captain to enter unexplored areas first to check ground conditions, mine atmosphere and temperature. The Captain first inspects the area that the team will be entering to make sure it is safe. After the inspection, the Captain allows the team to enter the area and directs their work in it.

The Vice-Captain will always be at the back end of the stretcher or last in line. In this position, the Vice-Captain can easily keep an eye on other team members to make sure they are proceeding without difficulty and can quickly halt the team if anyone appears to be in distress.

It is recommended that the team use the least obstructed travel way and stay in the intake air, wherever possible, as it advances. In multilevel mines, the team explores level by level, usually doing the drifts first and then the sublevels and stopes.

In single-level room and pillar mining, it is standard procedure to systematically explore all crosscuts and adjacent entries as they are encountered. That way, a team is never ahead of an unexplored area where a fire or toxic gases and smoke could close in behind them and cut off their retreat to safety.

Rate of travel

The speed that a team travels underground depends on many factors, including:

- Visibility (smoke);
- Climbing up and down raises or ramps;
- Obstructions in the travel ways such as;
  - parked machinery
  - cave-ins
  - water, and
  - slippery footing, etc.
- Whether or not vehicles are available for use;
- The amount of work to do (gas testing); and
- The load that the team is carrying (equipment, material, casualties, etc.)

The Captain should pace the team according to the conditions found. He should keep in mind that, if the team members have been doing strenuous work, they will be more tired and will require more rest periods on the way back to the fresh air base.

Travelling in smoke

Travelling in smoke is always difficult. Smoke will not only limit the team's rate of travel, but will also conceal hazards. Smoke can be so dense that the team will not be able to see loose backs and walls, parked equipment, or drop-offs.

For these reasons, it is recommended that team members use a link line at all times. The Captain should use a sounding stick to feel his way along and look for obstructions and hazards. If the team is exploring a wide entry and not carrying a stretcher, or when searching for injured persons, it is recommended that the other team members also use sounding sticks.

Teams working in dense smoke will sometimes encounter a phenomenon called "spatial disorientation." Dense smoke will conceal the backs, sides, or other reference points normally relied upon for guidance, causing workers to experience disorientation and lose all sense of direction and balance. Disoriented team members will then be more likely to be injured by bumping or running into things.

Visibility can be improved by removing the lamp from the cap and shining it close to the ground.
High intensity lights carried by the team or suspended on vehicles can be helpful in some instances. The disadvantage of wearing a light on the hat is that the light reflecting back off the smoke close to the face tends to blind the wearer.

The use of vehicle mounted or handheld thermal imaging cameras and laser pointers have been proven to be beneficial in dense smoke.

Travelling through water

When a team encounters water, the decision about how to deal with the problem is usually made at the control centre. If the water is not too deep and the team can get through it without danger, then it will probably just proceed through it. On the other hand, if it is possible to avoid the water by using an alternate route, it may be best to do so.

Careful consideration must be given to problems that flooding may cause, including:

- What effect will water have on electrical equipment?
- Is the water carrying flammable or toxic gases, such as hydrogen sulfide?
- Will the water flow increase?
- Should it be pumped out immediately?
- Is the water deep enough to submerge any breathing apparatus?

Electrical safety

Only qualified electrical workers may construct, install, alter, repair or maintain electrical equipment. To turn the power on or off:

- Do not stand directly in front of the switchbox;
- When pulling the switch, avert your eyes to avoid being exposed to any potential flash.

The whole team should stand back while the switch is being thrown. Be sure that you know what the results will be before throwing the switch and that the Coordinator knows your intentions.

Do not throw a switch in an explosive atmosphere. Have the power shut off from a remote location.

Blasting

Mine rescue workers should have a basic understanding of blasting, including blasting agents and detonators used at the mine. Rescue teams members should have a general knowledge of *the Mines Regulations, 2003* about explosives in a mine. The rescue team should be familiar with safety requirements for the explosives magazine.

Ground control

Proper roof and rib control measures can greatly reduce the dangers mine rescue teams face.

Inspection and testing

Roof support devices include timbers, posts, roof bolts, bolts, rebar, etc. Whether supported by auxiliary devices or not, the rescue team should visually inspect the area before entering a workplace.

Inspect the roof and ribs for:

- Stress cracks in roof, floor and rib;
- Failed rock bolts on the ground;
- Any abnormal rock formation;
- A formerly dry place that is now wet;
- Small chips or bark around timbers; and

- Moisture or cracks that may appear in the roof long after the area has been supported.

Scaling-checking backs and sides

Team members should make constant visual inspections of the back and sides for ground deterioration. Along with the visual checks, it is recommended that backs be sounded when:

- Poor visibility does not permit proper visual checks;
- Fallen slabs of loose roofs or backs are found on the floor;
- The backs have been subjected to extreme heat;
- The team intends to erect a seal, line-brattice, or post; and
- Travelling on or working any known bad ground area.

If a team encounters bad ground, it may have to scale, timber, or go around the area. It is standard practice to warn others by either marking or fencing off the hazardous area. The hazardous area should also be marked on the Captain's mine plan.

Inspect supports for:

- Crossbars, timbers and posts that are bent or under heavy pressure;
- Roof bolts that show signs of stress;
- Cap pieces squeezed down and over posts; and
- Timbers decayed through time.

Roof support devices

Roof support devices can be either temporary or permanent. Temporary supports may be timbers with cap blocks, screw type jacks, or hydraulic jacks. Temporary supports are used to support the roof:

- Before and during installation of permanent support at the face;
- During advance mining;
- When cleaning up after a roof fall;
- When replacing, adding, or removing permanent supports; and
- To ensure safety during pillar removal.

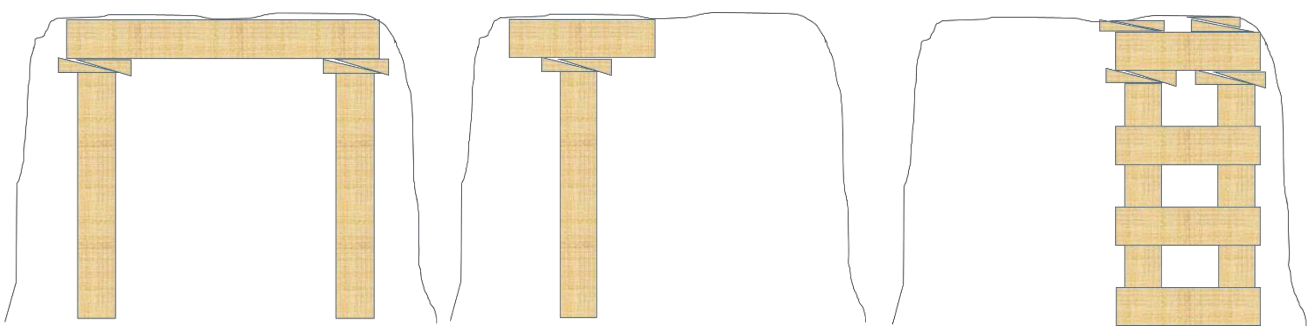
Ground support should not be installed by those not properly trained in the method used. Statistically, most ground fall injuries occur while scaling or securing bad ground. Improper ground support is hard to recognize and can lead a person to believe the ground has been secured when in fact it has not. This creates a hidden hazard which is often worse than leaving an obvious hazard.

Temporary supports should be no more than five feet apart. The roof should be tested and loose material taken down with a scaling bar before temporary supports are installed. The most common type of permanent roof support is the roof bolt. The conventional roof bolt is installed using a drill on a roof bolting machine. Another type of roof bolt is the rebar or resin (glue) bolt. To install a resin bolt, a hole is drilled as for conventional roof bolts. Then, long tubes of resin are inserted and the bolt is forced into the hole, breaking the tube. The bolt is held in place until the resin hardens.

In addition to roof bolts, various types of timber supports are used. Timber supports are called "conventional roof supports."

Timbering:

When it is not possible to avoid loose back conditions, it may be necessary to install temporary back support with timbers. Depending on the severity and location of the loose material, there are a number of types of timbering supports a team can install. If the loose is very localized in a small patch that cannot be scaled, a simple post and cap may be installed. If the loose spans the width of the back, a timber set may be needed. In extreme situations, the team may need to install one or more crib sets to stabilize the back.



Timber set | Post & cap | Crib

Testing the mine atmosphere

One of the most important considerations in mine rescue and recovery work is the condition of the mine's atmosphere. To determine the condition, you must monitor the atmosphere and find out if there are any harmful gases and what the volume and direction of the airflow is.

Mine rescue teams should never alter ventilation systems without direct orders from the control centre, unless the effects are known and all the people in the area are accounted for. Unauthorized or unplanned changes in ventilation could:

- Force deadly gases or smoke into areas where survivors are located;
- Force explosive gases over fire areas or hot spots;
- Cause an explosion;
- Redirect oxygen laden air into a fire; or
- Change the ventilation status of the fresh air base.

Gas detection

A team will make frequent tests for gases as it advances beyond the fresh air base. It will be necessary to determine what harmful gases are present, how much oxygen is in the atmosphere and whether or not gas levels are within the explosive range.

Testing is done with portable gas detectors, such as a:

- Multi-gas detector in conjunction with the appropriate tubes or chips; and
- Direct readout electronic detector.

These tests should be made at each intersection where conditions are unknown and at the furthest point of travel into each entry.

It may also be necessary to conduct gas tests when the team travels through a door or bulkhead beyond which conditions are not known. Sampling is done more often when potentially dangerous gas conditions are found.

Passing through ventilation doors and stoppings

A Team Captain should never alter any doors and ventilation stoppings unless he receives definite instructions to do so from the Coordinator. It should be agreed upon between the captain and the coordinator if minor changes can be made based on the circumstances by the team travelling through doors as a team and resetting the doors behind them. In most cases, there is a natural amount of leakage that attempting to back seal would prove to be changing the air anyway by completely stopping the flow.

When passing through ventilation doors and stoppings, follow these procedures:

1. On coming to the closed door, the Captain should halt the team and find out if anyone is behind the door by knocking on it.
2. Before the door is opened, careful consideration must be given to the possible consequences of opening it. Will opening the door:
   - Alter the direction and volume of airflow enough to force toxic gases into an area with trapped workers?
   - Provide fresh air to incipient fires?
   - Destroy a needed air lock?
   - If there are double doors, can the condition of the other door be determined?

3. The Captain should carefully try to determine the conditions behind the closed door by first feeling it for heat, or by looking through any regulators, man-doors, or windows. They should crack the door slightly while maintaining control of it to see if there are any immediate, drastic ventilation changes by doing so.
4. If there are no double doors to provide an air lock, and the ventilation change is sufficient to cause concern it may be necessary to erect a back seal or safety seal to create one.
5. The Captain or the Vice-Captain will open the door. The Vice-Captain will hold or secure the door while the Captain carefully leads the team through. The Captain will then halt the team, the door will be closed and the Vice-Captain will resume his position with the team.

Similar precautions are taken when a team passes through a ventilation stopping. Again, if needed, a safety seal will have to be erected to prevent an inadvertent change in the airflow or contamination of the unexplored area.

Once a team has passed through a door or a ventilation stopping, the door or stopping must be restored to its original position. These precautions should be observed whether a team travels with a vehicle or on foot.

Opening seals, barricades or doors

Opening a miner's seal

Two methods can be used to rescue personnel taking refuge behind a seal, barricade, or door. One way is to have personnel wear respiratory protective devices and the other is by ventilating the contaminated area and bringing the workers out bare-faced. It is always desirable to first ventilate the area, but this may take some time.

Using respiratory protective devices is much faster, but two precautions must be taken:

1. The trapped workers must be familiar with the respiratory protective devices.
2. An air lock must be built to ensure workers are not exposed to a burst of contaminated air when the door or seal is opened.

If workers are unfamiliar with the protective devices, or when such devices are unavailable, or cannot be worn due to injuries, it will be necessary to ventilate the contaminated area and bring the trapped personnel out bare-faced.

Bare-face exits require clearing the contamination by ventilation or erecting a line-brattice.
If a seal has not already been installed, a secondary or double seal should be erected against the miner's seal to make it air tight. This prevents the possibility of forcing contaminated air through the original miner's seal with the line-brattice.

Before an attempt is made to rescue the workers from behind the seal, the entry should be checked for toxic gases with a gas detector. Testing helps make sure that the workers can be brought out in safety. (See also "Rescuing survivors found behind a seal").

The procedure for opening a barricade or seal that has been erected to control a mine fire is entirely different than the procedure for opening a miner's seal. Opening a barricade or seal built to control a mine fire must only be done with the explicit orders and instructions of the Director of Rescue Operations. These procedures are explained in Chapter 4, "Dealing with Mine Fires."

Stretcher procedures

When exploring a mine on foot, supplies used by the team are usually carried on a basket type stretcher. The stretcher is also available for transporting injured workers found in the mine or an injured team member.

The work expected of the team and the situation in the mine determines the supplies and equipment that the team takes with it. Unnecessary equipment on the stretcher only tires the bearers. Equipment that a team might take along includes:

- Gas detectors;
- Air sampling instruments;
- Communication equipment;
- Long-link line or rope;
- Scaling bar;
- First aid supplies;
- Fire extinguisher;
- Blankets;

- Sufficient quantity of brattice;
- Tools: axe, hammer, nails, spad gun and spads, shovels, etc.;
- Breathing protection for missing workers;
- Two self-rescuers for the mine rescue team; and
- Spare oxygen bottles for breathing apparatus.

Four team members should share the load of the stretcher whenever the width and condition of the roadway permits. Frequent rests should be taken and team members allowed to change hands on the stretcher. At times, narrow roads and pathways may mean only two team members are able to carry the stretcher. Under such circumstances, more frequent rests and rotation of stretcher carriers will be required.

A stretcher limits the material and equipment a team can take on a mission. Carts or vehicles should be used when possible.

Link lines and safety lanyards

The link line, which could be a rope or lanyard, is a device used to keep team members from becoming separated. The members of the rescue team should be fastened together by means of an approved link line or safety lanyard when travelling in atmospheres where visibility is limited or may become so.

In some emergency situations, the link line may become a hazard. For example, when carrying a stretcher in cramped entries or giving first aid to a victim, it is permissible to disconnect the link line if team members keep in touch by some other means. Team members can maintain physical contact with each other by holding hands, or by hanging on to a life line or stretcher at all times.

Unless the link line is an approved fall arrest lanyard, fastened to a fall arrest harness this link line is not to be confused with fall protection.

Important: Team members must never become separated when visibility is poor!

Changing oxygen cylinders

If the air in a team member's oxygen cylinder runs out, the cylinder must be replaced. The steps in changing an oxygen cylinder are:

1. Remove the back cover; then use the bypass to fill the breathing bag or chamber.
2. Turn off the cylinder and use the bypass to bleed the line.
3. Once the line is bled, remove the cylinder and replace with a full one from the stretcher.
4. The new cylinder will pre-flush the system when opened.
5. Securely tighten the cylinder and then turn it on.
6. Replace cover.

Important: if the spare cylinder has to be used, there is a problem with the equipment and the team must immediately return to the fresh air base.

Diesel vehicles in mine rescue

During a mine disaster, time is of the essence. Often a mine rescue team can be better used if it travels over long distances using two diesel-powered vehicles. This requires some deviation from the procedures normally followed by a team.

Some allowance for procedural changes has to be made, but these changes must not be so critical as to endanger a team. Normally, the condition a team finds in the mine will dictate the procedures to be used. All procedures should be based on common sense and sound mine rescue principles so that the safety of the team and any workers in the mine is not endangered.

The advantages of using diesel vehicles during a fire are:

- Speed; teams can accomplish more work in less time;
- More equipment for firefighting and first aid can be carried;
- Less tiring for team members as they do not have to carry a stretcher, tools and material;
- Heavier, more sophisticated, modern gas monitoring devices can be carried;
- It is easier to transport casualties;
- Vehicles can be equipped with long-duration respiratory protective equipment for evacuating;
- Trapped and injured workers; and
- Vehicles can be equipped with high intensity lighting and heat sensing devices making it easier to
- Locate workers or fires.

The disadvantages of diesel vehicles are:

- Danger of travelling too great a distance from fresh air base; should the vehicle fail, the team might have to return on foot thereby overstaying time limits;
- Going too fast may result in overlooking ventilation checks at an intersection where smoke could cut off retreat;
- Possibility of vehicle failure;
- Teams may split up when using two or more vehicles;
- Seats on regular vehicles not suitable for personnel in apparatus;
- Specialized vehicles and equipment are usually not available in an emergency; and
- Not suitable in atmospheres containing heavy smoke or explosive gases.

Several types of diesel-powered vehicles are used for mine rescue work in Saskatchewan. Ordinary personnel carriers with seating modifications are used primarily for transportation. Others are sophisticated, custom built units used for firefighting and rescue.

Personnel carriers

Ordinary long-wheel base personnel carriers have been used satisfactorily in emergency situations. The only modification required is an alteration to the back of the driver's seat to allow comfortable operation while wearing an apparatus. The rest of the team members normally ride in the back of the vehicle with the stretcher.

Custom built vehicles

Several custom built vehicles are in use. These are not standard designs, but are built and equipped in accordance with the respective mine's specifications. These units may include a variation of the following:

- Seating capacity for at least five members of a mine rescue team wearing SCBAs;
- Sufficient room for a stretcher and one or two casualties;

- Firefighting equipment (portable dry chemical, extinguishers, large dry chemical tanks, AFFF solution, etc.);
- First aid boxes, splints and resuscitators;
- High intensity lighting and spot lights;
- Equipment and material for erecting stoppings;
- Auxiliary breathing protection (self-rescuers, face pieces and large air or oxygen cylinders);
- Scaling bars, axes, etc.; and
- Jacks.

Guidelines for using vehicles

Several procedures for using diesel vehicles in mine rescue work have been developed because every mine has its own, unique features. The following procedures should be thought of as “guidelines” rather than “rules”:

- The team should use two vehicles in case one breaks down;
- Members should be split-up with at least two persons on each vehicle;
- The distance between the vehicles should be as short as possible so that they can constantly communicate;
- Contact can be maintained by two-way radio, hand held horns, vehicle horns, lights and hand signals;
- The Captain should be on the lead vehicle and the Vice-Captain on the trailing vehicle; and
- The Captain and Vice-Captain should not be driving the vehicles.

Vehicles should not be used in heavy smoke. Teams should park the vehicles in good air and continue on foot where practicable.

Travel should be done in fresh air wherever possible. It is possible to travel in light smoke, but caution must be observed.

All contact points with the fresh air base must be prearranged. The Captain should make progress reports at these points and at regular intervals.

The distance traveled and the time required to walk this distance should be marked on the Captain’s and Fresh Air Base Coordinator’s plans. This gives the team an idea of how long they will have to travel on foot to get to the fresh air base if the vehicles break down or are abandoned for any reason (e.g., smoke, breakdown).

If the location of the fire and the contaminated areas are unknown, the approach must include the systematic exploration of all cross-cuts and adjacent entries. That way, as the team advances, it is never ahead of an unexplored, dangerous area. One vehicle is stationed at the main entry while the other inspects the cross-cuts. Both units must constantly be in contact with each other.
If the problem area is known and there is no danger of being “cut-off” by smoke, the team can proceed directly to it. Routes should be marked in the same manner as when travelling on foot. If the team is travelling in good air on the main route, it may not be necessary to fence off or mark every intersection, providing the Captain travels directly to the prearranged contact points and reports.

Continuous gas monitoring using direct read out gas analyzers can be carried on while the team advances. Tests can be made without getting off the vehicles, thereby saving time. Vehicles should not be used in atmospheres containing highly explosive gases.

Tests have been made to determine the least amount of oxygen that diesel vehicles need to operate. In one test, the engine was still running in 13 per cent oxygen, but the engine heat was almost unbearable for the operator. Experience shows that diesel engines can be successfully used in mine rescue work, but they have to be used with discretion and careful planning by those in charge of the mine rescue operation.

Care of survivors and recovery

While rescuing survivors may be the most rewarding job a rescue team does, no one enjoys recovering bodies. There is very little one can do to prepare for the associated emotional trauma.

Searching for survivors

Several questions should be asked before a rescue team enters a mine:

1. How many workers are missing?
2. What areas were they supposed to be working in?
3. Where are their escape routes?
4. Where are the workers likely to take shelter?
5. Where are the refuge stations? What supplies do they contain?
6. Are there any areas where the workers might go to obtain fresh air?
7. What is the company's evacuation procedure?
8. How much mine rescue and first aid training do the workers have?
9. What rescue supplies are available or stored in the mine? Where?

Survivors may be found in open entries, escape routes, shops, or refuge stations. They may be injured and unconscious, or apparently healthy and walking around. They may be trapped behind or underneath a piece of equipment, rock falls, debris, or other obstructions. They may have sealed themselves off behind seals or barricades. In hard rock mines, workers have often been found on the ramp.

It is important to both LOOK and LISTEN for clues when the team is searching for survivors. Survivors will often try to leave indications of where they are seeking shelter. These clues could be in the form of notes placed on equipment. There might be chalk or paint marks on the walls or doors. They may leave clues like covers from self-rescuers lying in the travel ways. Do seals or barricades appear to have been installed from the inside or outside? Workers may not be able to respond but how it was built may indicate their presence.

The rescue team should listen for noises, such as voices, or pounding on equipment, pipes, rails, walls, or cave-ins. When survivors are located, their location, identities and conditions should be reported immediately to the control centre and recorded on the mine plan.

Extrication equipment:

A hazards analysis should be done at every mine to determine the probability of accidents where extrication equipment may be required by mine rescue teams. Where such equipment may be required, it must be made available to rescue teams. Members of the team must also be trained in the use of such equipment.

Technical rope rescue:

A safety hazard analysis should be conducted at each mine for potential rope rescue requirements. If technical rope rescue is needed for mine rescue and recovery operations, established procedures must be followed such as those set out in the CMC Technical Rope Rescue training manual. The training must be given by an instructor qualified in Technical Rope Rescue.

Rescuing survivors found behind a seal

Survivors that have taken shelter behind a seal or in a refuge chamber should not be taken from this shelter until the route to the fresh air base is safe. An exception would be made if the survivors need immediate medical attention or their shelter is in danger. In such cases, the Captain determines the severity of the situation, sets priorities and issues instructions accordingly. For example, the Captain might deem that giving emergency first aid to stop severe bleeding or supplying survivors with respiratory protection is the immediate priority of his team.

Normally, the seal or the refuge station door is not opened unless absolutely necessary. When a rescue team comes across a miner's seal in a contaminated entry behind which survivors have taken refuge, the Captain will knock on it to determine the number of survivors and their condition. The seal should then be examined for air leaks to ensure that gases do not enter the refuge.

There are three courses of action that the Captain must consider:

1. *Leave the survivors behind the seal.* When the survivors are safe and the route to fresh air is contaminated, it may be best to leave them where they are until the air is cleared. A secondary or double seal should be erected and the survivors reassured before the team leaves them. Double sealing would also protect the miner's seal from changes in ventilation pressure during the ventilating process. Consideration must be given to the supply/duration of breathable air behind the seal.

2. *Remove the survivors immediately.* When survivors are in immediate danger or require emergency first aid and respiratory protection, the team may have to go through the seal without erecting an air lock. This decision would be made 'on-the-spot' by the Captain. Survivors would be warned to move away from the seal, if possible. The seal should then be opened just enough to admit a couple of the team members and then quickly resealed to prevent contamination of the refuge area. The survivors are then treated, supplied with respiratory protection and removed if necessary.

3. *Remove the survivors at the team's convenience.* When the team evacuates the survivors, two methods can be used. If the air in front of the seal is tested and found to be free of contaminants, the team will simply take down the seal and evacuate the survivors. If the atmosphere in the vicinity is contaminated, an air lock will have to be erected. The air lock should be placed as close as possible to the miner's seal. Again, an opening just large enough to permit entry should be made and quickly closed after the team passes through. The survivors can now be fitted with respiratory protection and taken to the fresh air base.

Survivors must be physically able to wear such breathing apparatus properly. Care should be taken to ensure that there are no facial injuries or vomiting. In such situations, it is best to leave the survivors in a refuge station or behind the seal until the mine is ventilated.

The mine rescue team must be certain that the survivors are trained and know how to use the breathing apparatus that they are expected to wear. Survivors may panic and attempt to remove their breathing apparatus while travelling in a toxic atmosphere.

Caring for survivors

When survivors are found, it is important for the team Captain to determine their physical condition and the condition of the atmosphere around them. The Captain must determine exactly what the team has to do to protect the injured and what treatment to give. If the atmosphere is questionable or dangerous to life, immediate respiratory protection must be provided. If possible, survivors should be moved to a location with a good air supply for treatment. Whenever safe passage to the fresh air base is not possible, the survivors should be taken to good air (e.g., in a refuge station, shop, dead end entry, etc.) and isolated until the entries are ventilated. Seals may have to be erected for this purpose.

If safe passage to the fresh air base is available, the survivors should be immediately taken there. The rescue of survivors depends on prevailing conditions. Care must be taken not to expose survivors to further harm. Survivors must be reassured that they will be properly looked after.

First aid must be properly and promptly administered to all of the injured. When survivors are found, their behavior may range from apprehension to hysteria. The best way to relieve psychological stress in survivors is to talk with them as soon as possible. It is most important that the talking and reassuring be continued. Survivors who lose contact with a rescue team may feel abandoned and try to escape to fresh air, even though it is unsafe.

It may be necessary to physically restrain irrational survivors to prevent them from injuring themselves or others. Safety of the team must be maintained, do not risk injury to team members by physically fighting with an irrational worker. Any type of struggle may affect the integrity of the rescuers' face piece seal.

Above all, survivors should not be left alone. Similarly, survivors should never be allowed to walk out on their own even if they appear to be in good shape. They need the support and assistance of team members when leaving the mine. Team members may even need to restrain an individual to prevent him from "bolting" for fresh air as it is neared.

If a survivor is able to walk, he should be positioned between two rescue team members and guided out. If the person is unconscious or unable to walk, use the stretcher.

First aid tasks

The mechanics and function of breathing: Many gases found in a mine during normal times are toxic even if inhaled for a short period of time in concentrations above the recognized safe limit.

At the time of a fire in an underground mine, great quantities of deadly gases can be quickly released. The biggest problem confronting the miner during a fire is protection from toxic gases. Even during normal operations, circumstances can cause gases to build up that make the air harmful to breathe.

Most dangerous gases have a harmful effect when being inhaled. Understanding what happens when we breathe helps us understand what must be done and why, to protect ourselves from dangerous gases.

The mechanics of breathing: When we inhale, the diaphragm and chest muscles pull away from the lungs. This has the same effect as the bellows on an accordion when they are pulled open. A vacuum is created in the lungs by this chest expansion and the outside air rushes in to fill the vacuum.

The air enters the body by way of the nose and throat (pharynx), passes through the voice box (larynx) and travels down the wind pipe (trachea) and bronchial tubes to the lungs. When we exhale, the muscles of the chest and the diaphragm push in against the lungs. Again, this has the same effect as when we push in on an accordion bellows. The air is forced out of the lungs, taking the same path to the outside as it took on entry.

Obviously, air can only get to the lungs if the passage ways are clear of obstructions and the muscular action needed for expansion and contraction of the chest cavity takes place.
Even during normal operations, circumstances can cause gases to build up that make the air harmful to breathe.

Some gases, when inhaled, can cause air passages to swell and become obstructed. These gases can also interfere with the muscular action that moves the chest and diaphragm.

The muscular action that causes us to breathe is controlled by a portion of the brain at the base of the skull. This portion of the brain is stimulated and controlled by the amount of carbon dioxide gas in the blood.

In summary, the mechanics of breathing are like a bellows. When the bellows contract, air is forced out. When the bellows expand, air is sucked in by the difference in air pressure. The bellows of our lungs are expanded and contracted by our chest muscles and diaphragm. Before air can enter the lungs, these muscles must be free to work and the passage ways clear of obstruction.

The function of breathing: Normal air contains a certain amount of oxygen and oxygen is required for life. Breathing secures the oxygen that our bodies require. Lungs make the oxygen available for use by the body.

Just as a fire cannot burn without oxygen, the energy-producing combustion and bodybuilding processes cannot occur without oxygen. Without oxygen, our bodies die. When oxygen enters the lungs, it is distributed to the millions of tiny air sacs that make up the lungs. These tiny air sacs, or compartments, have walls so thin that the oxygen can pass into the blood itself.

Blood is composed of red and white cells carried in almost colorless liquid called plasma. A part of the red cell called hemoglobin (pronounced heem-o-glow-bin) attracts oxygen. As blood circulation brings the red cells into contact with the air sacs of the lungs, the oxygen is attracted to the hemoglobin. The hemoglobin then carries the oxygen throughout the body, where it is used in the energy-producing combustion of the digested food stuffs.

On the blood's return trip to the lungs, it carries the carbon dioxide which is a waste product of the combustion of food. As the blood passes the air sacs in the lungs, it picks up more oxygen and the carbon dioxide is forced out of the blood into the air sacs. The carbon dioxide is then breathed out when we exhale.

Simply put, as we breathe, fresh oxygen is added to our blood and carbon dioxide filtered from it, through the air sacs in the lungs. Anything that interferes with the steady flow of oxygen to the tissues of the body will slow down or damage the body's function.

Oxygen therapy: Oxygen therapy is the administration of 100 per cent oxygen (by inhalation) to victims of asphyxia from gases, smoke fumes, drowning, collapse, suspended respiration from electric shock, oxygen deficiency and other causes. Oxygen given to a casualty is considered to be a drug and the rescuer must be trained and certified to administer it.

Oxygen therapy units are classed under two headings:
1. Those which act as inhalators only; and
2. Resuscitators that provide artificial respiration by mechanical control of the oxygen bottle pressure.

These may also be used as an inhalator if resuscitation is not required.

Oxygen inhalation equipment:

The inhalator consists of a 300 litre capacity "D" oxygen cylinder capable of delivering at least 10 litres of oxygen per minute. It is normally equipped with a yoke, pressure gauge, flow meter, delivery tube and a semi-open, valve-less, disposable mask.

Resuscitators (oxygen-powered mechanical breathing devices): These are oxygen-powered devices that apply artificial respiration automatically and meet CSA standards. The older style resuscitators (with the manual push button) should not be used for resuscitation. In recent medical evaluations, the following advantages of oxygen-powered devices were cited:

- Simplicity;
- Delivery of 100 per cent oxygen;
- Two hands can be used to maintain a mask fit;
- High flow rates permitting adequate ventilation in spite of the mask leaks;
- Elimination of personal contact with the victim;
- In an emergency, the IDLH masks can be used for hazardous atmospheres during mine rescue and recovery operations (See the section on rescue of workers who have taken refuge); and
- The casualty can be transported in a basket stretcher while being resuscitated.

The disadvantages include:

- The lack of readily available units; and
- Their dependence on compressed oxygen as source.

Fatalities

When the team encounters a body, its location is reported to the control centre, mapped and marked on the mine plan. Regulatory agencies must be notified.

Every effort should be made to not disturb the body or any possible evidence in the area. If it is absolutely necessary to move a body, it should be outlined with chalk on the floor, or the floor marked to show where the head and feet were. If there is more than one body, an identifying number is usually given to each.

If possible, a photograph can be taken. There are very small cameras and video equipment available. Care should be taken not to encumber the team with equipment that will only be used for "after incident" investigation.

Unfortunately, there is little that prepares a rescue team for what they will encounter while recovering a body. Team members should expect to see some very unpleasant sights. In some cases, bodies will have no obvious injuries, while others may be badly burned, or disfigured, or even dismembered. In addition, after death, the body goes through various changes and stages of decay.

Debriefing

When the team returns to the fresh air base, the team Captain talks with the Fresh Air Base Coordinator and the Captain of the incoming team. This consultation is done to exchange information about what the team, saw, found and the work it did. Maps are also compared to ensure that the markings correspond.

Debriefing is a very important part of a rescue team's work. Often, significant details that appeared to be unimportant while the team was underground, or were simply overlooked in the report to the fresh air base, come out during the debriefing.

After debriefing, the Captain of the team should discuss the next tasks to be undertaken with the Coordinator and the incoming Captain. He should point out any problems and warn of hazards still in the mine. Finally, before discharging the team, the team members should be briefed on how to deal with media representatives. No statements about an emergency should be made to the media by team members until a full investigation has been carried out.

Defusing and critical incident stress debriefing (CISD):

Following the completion of a mine rescue emergency response, a critical incident stress debriefing should be conducted with all personnel directly involved in the response. This CISD should be held within six hours of the end of the emergency response and be facilitated by a qualified professional.

Chapter Six - Survival Program

Recognizing emergencies

Mine workers must always be on the alert for unusual occurrences or emergencies. Early identification of a problem and the response to it, can mean the difference between life and death for everyone in the area.

It is extremely important that every worker be able to recognize the early signs of an imminent emergency, such as a fire, inrush of water, severe fall of ground, or an unusual gaseous condition. The following are some of the signs or indications of possible emergencies:

- Sudden changes in ventilation;
- Blasts of air, caused by a fall of ground or inrush of water;
- The odours of smoke or other contaminants;
- Unusual noises or explosions;
- Interruption of normal services such as power failures;
- Fire alarm/emergency warning system such as stench gas;
- Visual or audio warning; and
- Unusual hurrying of workers.

Important: Any of these signs could mean that something irregular or dangerous has happened and that quick action may be necessary to prevent loss of life.

Upon discovering a problem a worker should:

- Investigate the problem or report to the supervisor who should take control; and
- If the supervisor is unavailable and an alarm has still not been activated, an effort should be made to phone the hoist operator, dispatch centre, or mine officials.

If the situation is such that the worker believes that evacuation is warranted, or anytime the fire alarm warning system is activated, all work should cease. Workers should, without delay, implement the emergency procedures that are outlined in the company's emergency procedures manual.

Important: Normally, workers should not attempt to make their way to safety through smoky and heavily contaminated areas while wearing only the filter-type self-rescuers. Filter-type self-rescuers will only provide respiratory protection against low concentrations of carbon monoxide.

They do not provide protection against various other gases or an oxygen deficient atmosphere. A worker is usually far better off taking refuge behind a barricade in a safe and uncontaminated entry.

During a mine emergency, workers with basic knowledge and proper emergency training, who act in a calm, rational manner, have an excellent chance of surviving.

Filter-type self-rescuers

These are onetime use devices used for escape purposes only. The types commonly used are the MSA W-65 and the Drager FSR-810.

Rugged construction allows both to be carried by workers or mounted on mobile equipment ready for instant use. As part of underground orientation and ongoing refresher training for workers, the mine employer must familiarize each worker with the emergency procedures and the rescue equipment available. This includes self-rescuers available in the mine.

This type of rescuer consists of a small canister with a mouthpiece directly attached to it. The wearer breathes through the mouth, while the nose is closed by a clip. Filter-type carbon monoxide self-rescuers do not protect against noxious gases or a deficiency of oxygen. They work by converting dangerous carbon monoxide to carbon dioxide.

The presence of carbon monoxide in the air is indicated by heat generated in the self-rescuer when it is being worn. Both types of respirator will provide adequate protection for 60 minutes in air with a 1 per cent concentration of carbon monoxide.

At 1 per cent or higher carbon monoxide concentrations, heat generated by the chemical reaction with the hopcalite in the self-rescuer will make breathing practically unbearable. All units have a built-in heat exchanger to help reduce the temperature of the air reaching the wearer's mouth.

Follow the manufacturer's instructions for use of self-rescuers.

Self-Contained Self-Rescuers (SCSR)

A self-rescuer has or is able to generate its own supply of oxygen. Types commonly used are the MSA Auer SSR30/100 and the Ocenco M-20. These are generally good for 20 minutes to one hour of use, depending on the type and how hard the wearer is working.

Rugged construction allows SCSRs to be carried by personnel while at work or be mounted on mobile equipment ready for instant use. These units are compact and isolate the user's lungs from the surrounding atmosphere. They use compressed or chemically produced oxygen to provide respiratory protection. These are easy to activate and don.

Important: The self-rescuer must be kept on and used, regardless of the heat generated, until the wearer reaches safety.

Taking shelter behind seals

When workers have been trapped by fire in a mine, they must not rush about aimlessly. All workers in an emergency must take immediate action to protect themselves.

When the way of escape is cut off, but the local atmosphere is still uncontaminated, consideration should be given to building a temporary refuge. The refuge will isolate the workers from the air in the rest of the mine and provide a safe location where they can wait for the rescue teams to arrive.

If the worker is in a dead-end entry, it may be possible to get temporary protection by short circuiting the airflow to the face by:

- Shutting off the local auxiliary fans that supply air to the face;
- Breaking the ventilation ducting;
- Breaking the line-brattice;
- Tearing down the brattice stoppings at intersections, cross-cuts, or breakthroughs and redirecting the airflow; or
- Opening the compressed air line (many lives have been saved this way in hard rock mines).

For maximum safety, seals or barricades are required. They should be erected without delay as dangerous gases often travel quickly. The time required to build an efficient seal depends on conditions in which it is being built.

Anything that might be useful for erecting the seal, or needed while in isolation, should be collected, including items such as:

- Tools;
- Timber;
- Canvas;
- Ventilation tubing;
- Brattice material;
- Water;
- Lunch kits; and
- Cap lamps.

The area chosen for refuge should meet the following requirements:

- If compressed air is not available, the area should enclose the maximum practicable volume.
- Each person uses approximately one cubic metre of air per hour. The sealed area should include as much territory as possible, including long entries and cross-cuts.

Before constructing seals, make sure there are no other openings or connections to other workings that gases can enter through. It may be necessary to construct seals at more than one end of the entry.

If possible, the sealed area should include a telephone and compressed air line and valve. The telephone allows trapped workers to talk with the mine officials on surface. The air- line supplies compressed air to the refuge area.

Seals can be constructed of any material that is available, such as:

- Brattice seals;
- Cut up ventilation tubing;

- Canvas;
- Cloth; or
- Timber.

In potash mines, most work areas should be stocked with an ample supply of brattice, spad guns and spads for such emergencies. After the seal has been built, the workers should keep as still as possible.

People use several times more oxygen when exerting themselves as they do when at rest. However, one person should walk around occasionally to mix the air. Workers should not gather in one place. Electric batteries, water and food should be conserved.

Smoking must be prohibited!

Before going into isolation behind the seal, workers should try to get a message to the surface. Such a message would report:

- Where the workers are trapped;
- The names and numbers of trapped workers; and
- Their condition.

A sign should also be placed outside the stopping giving the names and tag numbers of the workers inside. If circumstances permit and materials are readily available, a second seal should be erected inside the first to provide an air lock.

Under no circumstances should workers attempt to leave their place of refuge! They must stay in the refuge until the rescue team or supervisor comes for them.

Refuge stations

Every underground mine in Saskatchewan must install, equip, operate and maintain such refuge stations as are necessary to protect the workers. Permanent refuge stations must be provided with food, water, air, first aid supplies, sanitation supplies, lighting and telephone communications to surface. Temporary refuge stations contain more limited supplies, but communication with the surface is also required.

Refuge stations vary in size and should have the volume to provide air for a large number of people without any additional supply of fresh air or oxygen. As a general rule, where there is no source of compressed air, a worker at rest will require 1 cubic metre of air per hour. In the hard rock mines, refuge stations are smaller than in the potash mines but they are supplied with compressed air lines from surface

In all cases where workers are forced to seek refuge, proper procedures must be employed:

- Workers should carry their lunch and water, as well as available respirators, to the station;
- Communication should be established with the surface;
- The location of the refuge station and the number and names of the workers in it should be reported as soon as possible; and
- All nonessential activity in the station must stop to conserve oxygen and reduce CO_2 production.

Once the station is sealed, workers in the station should not emerge until the atmosphere outside the station is checked by mine rescue teams or the “all clear” is given by the authorized authorities.

The types of refuge stations provided in Saskatchewan are as follows:
Permanent type: Usually a stub or drift is cut in the rock and closed at each end with permanent bulkheads and man doors. This type of refuge station is usually strategically located and is large enough to accommodate all the workers in the area.

Portable type: Portable or moveable steel or fiberglass enclosures are usually provided for remote areas in the mine and where travel to a central refuge station is uncertain or unsafe. These units are small enclosures designed for from six to ten workers. They are usually located very close to a work area. This type of refuge station is generally equipped with compressed air or oxygen and a CO_2 absorbent to compensate for the limited air content.