Advanced
Mine Rescue Training

Mine Gases

Module 2

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Course Objectives

The mine rescue team members will distinguish the physical properties and characteristics of gases they may encounter during rescue and recovery work.

They will explain where the gases are normally found, conduct tests for dangerous gases, and interpret their findings.

Team members will:

- Use these concepts: Specific gravity, explosive range, toxicity, asphyxiate, and solubility.
- Explain the physical properties and characteristics of each gas they may encounter following a fire, explosion, inundation, or other disaster.
- Analyze the mine for locations where such gases might be found, conduct tests to detect them, and explain the meanings of their findings.
- Explain the composition, physical properties, and characteristics of smoke, rock strata gases, and the damps.

Course Materials

Required:

- Visuals/handouts from the back of this module
- Pencil and paper for each team member
- Gas detecting equipment and devices the team will use to test gases they encounter in the mine, and the manufacturer's instructions
- IG 7a – Advanced Skills Training Activities for Coal Mine Rescue Teams

Suggested:

- Evacuated bottle or syringe for taking air samples
- Laptop computer
- PowerPoint program
- Chalkboard or flipchart

NOTE: In addition to these materials, you are encouraged to incorporate any other up-to-date supplemental mine rescue instructional materials, handouts, and/or methods that will increase the effectiveness and retention of the training.

Course Outline

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Instructional Text

Introduction

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

Gas Detection

Gas detection is an important part of any rescue or recovery operation. Your team will make frequent tests for gases as it advances beyond the fresh air base. For your own safety, you'll want to know what harmful gases are present, how much oxygen is in the atmosphere, and whether or not gas levels are within the explosive range.

Knowing what gases are present and in what concentrations provide you with important clues as to what has happened in the mine. Test results can also give you an idea about existing conditions.

For example, if you get carbon monoxide (CO) readings, there's probably a fire. The amount of carbon monoxide indicates something about the extent of that fire.

Gas Detector Requirements

Regulations require mine rescue stations to have four gas detectors appropriate for each type of gas that may be encountered at the mines served. Gas detectors must measure concentrations of methane from 0.0 percent to 100 percent of volume, oxygen from 0.0 percent to at least 20 percent of volume, and carbon monoxide from 0.0 parts per million to at least 9,999 parts per million (**30 CFR Section 49.16(a)(6)**).

Portable Gas Detectors

The type of gas detection equipment most often used by mine rescue teams is the portable gas detector. Portable gas detectors include such devices as carbon monoxide (CO) detectors, multi-gas detectors used in conjunction with various tubes, and methane monitors used in mines with methane. The team uses these devices to test the mine air repeatedly as it advances beyond the fresh air base. **NOTE:** Show the team members the portable gas detectors they may be using.

Air Sampling and Chemical Analysis

Another way to test for gases is to collect air samples in special syringes, evacuated bottles (bottles from which air has been removed) or gas or liquid displacement containers. These samples are then sent to a laboratory for chemical analysis. Chemical analysis is sometimes performed at the mine site with portable equipment.

NOTE: Show the team a syringe or evacuated bottle, if available, or use the graphic provided **(Visual 2)**.

Chemical analysis is generally a more time-consuming process than testing with a portable device, but its advantage is accuracy. It tells exactly what gases the sample contains, and in precisely what amounts. A complete chemical analysis can also reveal the presence of gases that portable detectors are not designed to detect.

Air samples aren't taken as often as portable detector readings, but they're still an important part of rescue and recovery operations. For example, you may be required to take air samples from ventilation shafts and return airways.

This method is often used to get information about existing conditions prior to sending teams underground. Air samples taken from behind sealed areas of the mine are analyzed to determine when it's safe to begin recovery work.

Basic Gas Principles

In order to test for gases and to understand what the test readings mean, you should first know a little about the characteristics and properties of gases. After we've discussed these general principles, we'll talk about specific gases you may encounter during rescue and recovery work.

Description

To help you understand what a gas is, let's compare it with a liquid and a solid. A solid has a definite shape and volume. A liquid has a definite volume, but changes shape according to the shape of its container. However, a gas is a substance with neither a definite shape nor volume. It expands or contracts to fill the area in which it's contained.

Diffusion of Gases

The volume of a gas changes in response to any change in atmospheric pressure or temperature. For example:

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

NOTE: Refer to **Visual 3.**

The gas's rate of diffusion is also affected by the ventilating air currents in the mine. The rate of diffusion is greatly increased by higher velocities of air currents or by turbulence in the air.

Knowing the effects of air current, temperature, and pressure on a gas will help you determine its rate of diffusion. The rate of diffusion is how quickly the gas will mix or blend with one or more other gases and how quickly it can be dispersed.

Atmospheric Pressure and its Effects on Rate of Diffusion

Pressure exerted on a gas is usually atmospheric pressure. Atmospheric pressure is measured on a barometer. A rise in the barometric reading indicates an increase in pressure. A drop in barometric reading indicates a decrease in pressure. The atmospheric pressure varies within a mine, just as it does on the surface.

Atmospheric pressure affects the diffusion rate of a gas. For example, if the barometer rises, indicating increased pressure, gas responds by contracting.

A gas that's squeezed into a smaller area like this is more concentrated, so it diffuses more slowly.

NOTE: Refer to **Visual 4** for an illustration of the effects of atmospheric pressure on a gas.

It's much easier for concentrations of explosive gases to build up when the barometric pressure is high. On the other hand, when barometric pressure falls, the pressure on the gas is reduced. The gas responds by expanding. Once the gas expands, it is less concentrated, so it diffuses more quickly.

Temperature and its Effects on Rate of Diffusion

It's important to understand how temperature affects the rate of diffusion of a gas. High temperatures (or heat) cause gases to expand, so they diffuse more quickly. Consequently, heat from a fire in the mine will cause gases to expand and be dispersed more easily. Lower temperatures work the opposite way: Gases respond to cold by contracting and by diffusing more slowly.

NOTE: Refer to **Visual 5** for an illustration of the effects of temperature on a gas.

Specific Gravity or Relative Weight

Specific gravity is the weight of a gas compared to an equal volume of normal air under the same temperature and pressure. (This is also referred to as "relative weight.") The specific gravity of normal air is 1.0. The weight of air acts as a reference point from which we measure the relative weight of other gases. For example, a gas that is heavier than air has a specific gravity higher than 1.0. A gas that is lighter than air will have a specific gravity less than 1.0.

NOTE: Refer to **Visual 6.**

If you know the specific gravity of a gas, you will know where it will be located in the mine and where you should test for it. Gases issuing into still air without mixing tend to stratify according to the gas's specific gravity. Light gases or mixtures tend to stratify against the roof and heavy gases or mixtures tend to stratify along the floor.

NOTE: In this module, specific gravities **are carried out to four digits.** You may wish to round these numbers off to make them easier to work with.

Methane, for example, has a specific gravity of 0.5545. This is lighter than normal air. Knowing this, you can predict that methane will rise and collect in greater concentrations near the top or roof of a mine. This is why you test for methane near the top.

Sulfur dioxide has a specific gravity of 2.2638. This is much heavier than normal air. Knowing this, you can predict that sulfur dioxide will collect in greater concentrations near the bottom or in low areas of a mine. This is why you test for sulfur dioxide in low areas of the mine.

If the weight of a gas you're testing for is lighter than normal air, you'll know to test for it within 12 inches of the mine roof. That's because lighter gases tend to rise, so you can expect to find them in greater concentrations in high areas of the mine.

Besides helping you determine where to test for a gas, specific gravity also indicates how quickly the gas will diffuse and how easily it can be dispersed by ventilation. In still air, the ordinary process of diffusion is a very slow process.

However, under usual mine conditions, ventilating air currents and convection currents produced by temperature differences cause a rapid mechanical mixing of gases with air. Once the gases are mixed, they will not separate or stratify again.

Light gases, such as methane or hydrogen, diffuse rapidly and are fairly easy to disperse. Heavier gases such as sulfur dioxide and carbon dioxide do not diffuse rapidly, so they're more difficult to disperse.

It's much easier to remove a concentration of a light gas like methane by ventilation than it is to remove the same concentration of a heavier gas like carbon dioxide.

NOTE: Refer again to **Visual 3 and Visual 4**, as you review the effects of temperature and pressure on rate of diffusion.

Specific gravity is not the only factor that determines how quickly a gas will diffuse or disperse. Temperature and pressure also affect it. An increase in temperature makes a gas diffuse more rapidly. A decrease in temperature slows down the rate of diffusion. Atmospheric pressure works just the opposite: An increase in pressure slows down the rate of diffusion. A decrease in pressure speeds it up.

Explosive Range and Flammability

A gas that will burn is said to be "flammable." Any flammable gas can explode under certain conditions. In order for a flammable gas to explode, there must be enough of the gas in the air, enough oxygen, and a source of ignition.

The range of concentrations within which a gas will explode is known as its "explosive range." Figures representing the higher and lower limits of the explosive range are expressed in percentages.

The amount of oxygen that must be present for an explosion to occur is also expressed as a percentage. When the necessary oxygen concentration approaches that found in normal air, the level is expressed simply as "normal air."

The explosive range of methane, for example, is 5 to 15 percent in the presence of at least 12.1 percent oxygen.

Solubility

Solubility is the ability of a gas to be dissolved in water. Some gases found in mines are soluble and can be released from water. Sulfur dioxide and hydrogen sulfide, for example, are water-soluble gases. Both may be released from water.

Solubility is an important factor to consider during recovery operations. When a mine is sealed off for any length of time, water can collect in it. This water may have occurred naturally, or it may have been introduced during firefighting.

Whatever the case, pools of water can release water-soluble gases into the air when they are stirred up. Pumping water from such pools, or walking through them, can release large amounts of soluble gases which would not otherwise be found in the mine atmosphere.

Color/Odor/Taste

Color, odor, and taste are physical properties that can help you identify a gas, especially during barefaced exploration. Hydrogen sulfide, for example, has a distinctive “rotten egg” odor. Some gases may taste bitter or acid; others sweet. The odor of blasting powder fumes, together with a reddish-brown color, indicates there are oxides of nitrogen present.

Of course, you can’t rely on only your senses to positively identify a gas. Only detectors and chemical analysis can do that. Many hazardous gases, such as carbon monoxide, have no odor, color, or taste. Keep these properties in mind as we discuss each gas you may encounter in the mine. One or more of these properties may be your first clue that a particular gas is present.

Health Hazards

Toxic Gases

Some gases found in mines are toxic (poisonous). This can refer either to what happens when you breathe the gas, or what happens when the gas comes into contact with exposed areas of your body.

NOTE: Refer to **Visual 7** as you discuss the factors that determine the effects of a toxic gas.

The degree to which a toxic gas will affect you depends on three factors:

(1) how concentrated the gas is,
(2) how toxic the gas is, and
(3) how long you're exposed to the gas.

NOTE: You may wish to mention that each toxic gas has a **Threshold Limit Value (TLV).** TLVs denote average concentrations of gases to which workers are permitted to be exposed over an 8-hour daily period. The Threshold Limit Value (TLV) of a gas is expressed in **"parts per million" (PPM).**

For example, the TLV for carbon monoxide (CO) is relatively low—50 PPM (or .005 percent). This means that the most CO you can be exposed to over **an 8-hour daily period without harmful effects is 1/200 of one percent.** That isn't much. The TLV for carbon dioxide (CO_2) is higher—5,000 PPM (.500 percent). You can tolerate concentrations of up to ½ of 1 percent CO_2 over an 8-hour daily period without harmful effects.

Some toxic gases are harmful to inhale. A self-contained breathing apparatus (SCBA) will protect you from such gases, as long as your face-to-facepiece seal is tight. Other toxic gases harm the skin or can be absorbed by the skin. An SCBA won't protect you from such gases. If you wear your SCBA in petroleum-based fumes for prolonged or successive periods, the fumes can eventually permeate its rubber parts so that the apparatus no longer provides you with adequate protection. Your team may be forced to leave an area where such gases are detected.

Asphyxiating Gases

"Asphyxiate" means to suffocate or choke. Asphyxiating gases cause suffocation. They do this by displacing oxygen in the air, thus producing an oxygen-deficient atmosphere. Since your self-contained breathing apparatus supplies you with oxygen, it will protect you against asphyxiating gases.

Review Questions: Ask the team members the following questions and allow time for them to answer. Then discuss the answers with them so they understand the material covered in this section.

1. How do temperature and pressure affect a gas, and how do these factors affect mine rescue?

   Answer: Temperature increases cause expansion. Temperature-decreases cause contraction. Pressure-increases cause contraction. Pressure-decreases cause expansion. Implication: These factors affect the diffusion rate of gases in the mine.

2. What is specific gravity?
   Answer: The specific gravity (or relative weight) of a gas is its weight in relation to an equal amount of normal air under the same temperature and pressure.

3. What can you determine if you know the specific gravity of a particular gas?
   Answer: Specific gravity determines where the gas will stratify in still air in the mine (whether it will rise or fall). It also determines how easily a gas can be diffused or flushed out of the mine by ventilation.

4. What is the explosive range of a gas and why is it important for rescue team members to know the explosive range of gases they encounter?
   Answer: The explosive range of a gas is the concentrations within which a flammable gas can explode when there is a specific amount of oxygen present. It's important for you to know the explosive ranges of gases you encounter and the amount of oxygen necessary for an explosion so you will immediately know when you encounter a potentially explosive atmosphere.

5. What is a toxic gas?
   Answer: A gas that is capable of causing damage to living tissues, impairment of the central nervous system, severe illness or, in extreme cases, death when it is ingested, inhaled, or absorbed by the skin or eyes.

6. How can you protect yourself from toxic gases?
   Answer: Wearing a self-contained breathing apparatus (SCBA) will protect you from many of them. However, an SCBA does not provide you with protection against gases that attack the skin or enter the body through the skin. Neither will it provide protection if you wear it for prolonged or successive periods in petroleum-based fumes, because such fumes may permeate the rubber. In the presence of such gases, your team may be forced to leave the area of the mine where they're located.

7. How does an asphyxiating gas produce an oxygen-deficient atmosphere?
   Answer: It displaces oxygen.

8. How do you protect yourself in an oxygen-deficient atmosphere?
   Answer: Wear an SCBA, which supplies you with oxygen.

9. Why is it important for you to know about the solubility of certain gases in water?
   Answer: Gases dissolved in water can be liberated in large quantities when mine rescue teams disturb the water by walking through it, or by beginning pumping operations.

10. Why should you know about the characteristic color, odor, and taste of gases you may encounter?
    Answer: The characteristic color and, if the team is barefaced, odor or taste of a gas may be the first clue a rescue team has that the gas is present in the mine atmosphere.

Mine Gases and Their Detection

NOTE: Refer to **Visuals 8 through 18,** as you discuss mine gases and detection methods. Make copies of each visual and distribute them to the team members.
If the team may encounter a gas that's **<u>not</u> included here**, be sure to supply them with information on that gas. Use the sample fill-in gas chart **(Visual 19)** as a guide. Fill in the chart as needed with the correct information.

Normal Air

The air we breathe is actually a mixture of gases. Clean, dry air at sea level is made up of 78 percent nitrogen and 21 percent oxygen. The remaining one percent is made up of argon, carbon dioxide, and small traces of other gases. Other gases in air are: neon, helium, krypton, xenon, hydrogen, methane, nitrous oxide, and ozone.

NOTE: Refer to the pie chart **(Visual 8)** showing the composition of normal air.

Air is normally colorless, tasteless, and odorless. It supplies us with the oxygen necessary for life. However, during the day-to-day operations of a mine, normal air can become contaminated. For example, the carbon dioxide and water vapors miners exhale during respiration are contaminants.

Forces exerted on the mine's roof, rib, floor, and face during blasting may allow trapped gas pockets to escape into the mine air. Blasting may also produce pollutants such as carbon monoxide, hydrogen sulfide, and oxides of nitrogen.

Even internal combustion engines and battery-charging stations can be sources of contamination because they can produce hazardous fumes. Normally, these contaminants are carried away by the mine's ventilation system. But during a disaster situation, the mine's ventilation system may be partially or totally disrupted.

Fires and explosions can disrupt ventilation by damaging ventilation controls. Falls and rock bursts can disrupt ventilation by obstructing the flow of air. In addition, the disaster itself may provide additional sources of contamination.

Fires and explosions, for example, often produce dangerous gases. Inundations may release water-soluble gases.

The gases present in a mine following a disaster will vary according to the type of mine and the disaster situation. The type of equipment used in the mine (electrical, compressed air, or diesel) will also affect which gases are present. However, for all mines, rescue teams **must** know how to test for oxygen deficiency and carbon monoxide.
In addition to this, the teams may have to know how to test for hydrogen sulfide, oxides of nitrogen, and so on. You should know how to test for all the gases that may be present in the mines in which you will be working as a mine rescue team.

NOTE: Refer to **manufacturer's instructions and recommendations** for the use and maintenance of specific testing devices. It's suggested that you discuss gas-testing equipment and devices **only after** you've discussed all the gases the team may encounter.

Oxygen (O_2)

Specific Gravity. 1.1054

Explosive Range and Flammability. Oxygen is not an explosive gas, but it does support combustion.

Health Hazards. Oxygen found in normal air is nontoxic. In fact, it is essential for life. It is harmful to breathe air that is low in oxygen, and breathing extremely oxygen-deficient air can kill you.

For example, you're accustomed to breathing air containing about 21 percent oxygen. When the oxygen content of air drops to about 17 percent, you'll begin to breathe faster and deeper because your body is trying to compensate for the lack of oxygen. A 15 percent concentration will cause dizziness and headaches. If the oxygen content of the air you're breathing drops as low as 9 percent, you may lose consciousness. A 6 percent concentration or less is almost always fatal.

There are five main causes of oxygen deficiency in the mine: (1) insufficient or improper ventilation which fails to bring enough oxygen to the work area, (2) displacement of the air's oxygen by other gases, (3) a fire or explosion that consumes oxygen, (4) the absorption of oxygen by coal, particularly at freshly cut faces, and (5) consumption of oxygen by workers.

Solubility. Moderately soluble in water.

Color/Odor/Taste. Colorless, odorless, and tasteless.

Cause or Origin. Oxygen is the second largest component of normal air. About 21 percent of normal air is oxygen.

Carbon Dioxide (CO_2)

Specific Gravity. 1.5291

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

Health Hazards. Normal air contains about 0.03 percent carbon dioxide.

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

Solubility. Carbon dioxide is soluble in water.

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

Cause or Origin. Carbon dioxide is a normal component of air and is a product of complete combustion (burning). Oxidation and the decay of timbers also produce carbon dioxide. Carbon dioxide is also a by-product of the respiration (breathing) process. Fires, explosions, and blasting operations produce CO_2. In some mines, it is liberated from the rock strata.

Where Found. Because it's relatively heavy, CO_2 will be found in greater concentrations along the floor and in low places in the mine. It also often shows up in abandoned workings, during fires, and after an explosion or detonation of explosives.

Detection Methods. You can use a carbon dioxide detector, a multi-gas detector, or chemical analysis to test for carbon dioxide. Because CO_2 tends to collect near the mine floor, hold your portable detector low.

When to Test. Test for CO_2 after a fire or explosion. Also test for it when you're entering an inactive area of the mine or reopening a sealed area.

Meaning of Findings. Elevated CO_2 readings may indicate that a fire or explosion has taken place somewhere in the mine. High readings may also indicate an oxygen-deficient atmosphere.

Detection Methods. Modern electronic oxygen indicators are used to detect oxygen-deficient atmospheres. Since oxygen is only slightly heavier than air, hold your portable detector at waist level when you test for oxygen deficiency. Chemical analysis will also detect oxygen deficiency.

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

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

Methane (CH_4)

Specific Gravity. 0.5545.

Explosive Range and Flammability. Methane is flammable. Its explosive range is 5 to 15 percent when there is at least 12.1 percent oxygen. Methane is most explosive, however, in the 9.5 to 10 percent range.

Methane's explosive range is not an absolute measure of safety. There are several other important factors to take into consideration. For example, the presence of other combustible gases with wider explosive ranges or lower ignition points than methane may result in a more highly explosive mixture.

Coal dust in the air also lowers methane's explosive limits. A mixture containing as little as 1 ½ to 2 percent methane, together with coal dust, may be explosive.

Because moisture tends to keep dust levels down, dust will be more of a problem underground in the winter months when the mine air is less humid.

Note: Cold dry air from outside a mine will be warmed as it goes through the mine. Warm air will hold more water vapor than cool air, so therefore it picks up moisture from inside the mine. This will cause a dry condition in the mine even though the humidity is higher underground than on the surface.

Health Hazards. Methane is not toxic. In high concentrations, however, it can cause asphyxiation by lowering the oxygen content of normal air. The most dangerous aspect of methane is the fact that it is explosive.

Solubility. Slightly soluble in water.

Color/Odor/Taste. Colorless, odorless, tasteless.

Cause or Origin. Methane is the most common flammable gas found in coal mines. It is a normal component of coal, originating from the decomposition of vegetable matter during its formation.

Methane can be liberated in large quantities from feeders and blowers or from clay veins in coal mines. It's also often liberated from virgin (uncut) coal and released from freshly broken coal faces.

Where found. Because methane is relatively light, it collects in high places, so you can expect to find it in roof areas of the mine. You'll also normally find it at freshly cut faces, in poorly ventilated areas, and in abandoned or unused sections of the mine.

Other Information. There is usually more methane in deep workings than at the outcrop. Deeper mines also usually contain more methane than shallow ones, and shaft mines contain more methane than drift mines.

You can expect to find more methane in coal beds that are adjoined by tight, compact strata than in coal beds adjoined by loose or porous strata. Methane is also a problem in areas of faulting of the coal seam.

You'll generally also find more methane in regions where the strata is uniform and unbroken rather than where the strata is folded or broken. Mines below the water table tend to have more methane than those above the water table. Because it is a relatively light gas (low specific gravity), methane is usually easy to disperse and remove from the mine by means of ventilation.

Detection Methods. To test for methane, use a methane detector or chemical analysis. Remember that methane is a light gas, so hold your portable detector high.

Where to Test. During any team exploration, test as often as necessary to determine the methane content of the surrounding atmosphere. Also test for methane when normal ventilation is disrupted, and when you are entering abandoned workings.

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

Carbon Monoxide (CO)

Specific Gravity. 0.9672

Explosive Range and Flammability. Carbon monoxide is explosive and flammable. Its explosive range in normal air is 12.5 to 74.2 percent.

Health Hazards. Carbon monoxide is highly toxic even in very low concentrations. Exposure to as little as .15 to .20 percent CO is extremely dangerous. Carbon monoxide is so toxic because it combines easily with your red blood cells (hemoglobin)—the cells that normally carry oxygen to your body's tissues. Once the cells have taken up CO, they no longer have the capacity to carry oxygen.

It doesn't take much CO to interfere with your blood's oxygen-carrying capacity because the gas combines with hemoglobin 200 to 300 times more readily than oxygen.

The first symptom of carbon monoxide poisoning is a slight tightening across your forehead and possibly a headache. Carbon monoxide poisoning is cumulative over time. As you continue to be exposed to it, the poisoning effects build up accordingly. As little as 500 PPM (0.05 percent) can kill you in three hours. If you're exposed to a high CO concentration, you may experience very few symptoms before losing consciousness.

Solubility. Carbon monoxide is slightly soluble in water.

Cause or Origin. Carbon monoxide is a product of the incomplete combustion of any carbon material. It is produced by mine fires and explosions of gas.

Carbon monoxide is produced by the burning or detonation of explosives, and it is emitted from the exhaust of internal combustion engines.

NOTE: You may wish to mention that **carbon monoxide is the deadly gas associated with automobile exhausts.**

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

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

When to Test. During any team exploration, test as often as necessary to determine the atmosphere's CO content, especially if fire is suspected.

Meaning of Findings. The presence of CO for a continued period of time definitely indicates there is a fire somewhere in the mine.

Nitrogen (N_2)

Specific Gravity. 0.9674

Explosive Range and Flammability. Nitrogen is not an explosive gas and it will not burn.

Health Hazards. Nitrogen is nontoxic. However, in above-normal concentrations, it acts as an asphyxiant, because it lowers the oxygen content of the air.

Cause or Origin. Normal air contains approximately 78 percent nitrogen, making nitrogen the largest component of normal air. Underground, nitrogen levels may increase as coal faces adsorb oxygen. Gas blowers and feeders may give off nitrogen, and nitrogen is also released from coal during mining. Another source of nitrogen in underground mines is the detonation of explosives.

Where Found. You can expect to find elevated nitrogen readings at the face areas because they adsorb oxygen. Increased nitrogen levels are often present after explosives have been detonated.

Detection Method. Chemical analysis.

When to Test. Test for nitrogen when you suspect that the atmosphere is oxygen-deficient, and in abandoned or inactive workings where ventilation is inadequate. Also test for it in mines where nitrogen is known to issue from rock strata.

Meaning of Findings. An elevated nitrogen content indicates an oxygen-deficient atmosphere.

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

Specific Gravity. (NO_2) – 1.5894

Explosive Range and Flammability. NO_2 will neither burn nor explode.

Health Hazards. Oxides of nitrogen are highly toxic. Breathing even small amounts will irritate your throat.

When mixed with the moisture in your lungs, oxides of nitrogen form acids that corrode your respiratory passages and cause them to swell. Often, such symptoms don't show up until several hours after you're exposed to the gas.

Exposure to .01 to .015 percent can be dangerous for even short exposures, and .02 and .07 can be fatal for short exposures. If exposure has been severe, the victim may die, literally drowned by water that has entered the lungs from the body in an attempt to counteract the corrosive effects of the acids formed by the oxides of nitrogen.

Solubility. Very slight solubility in water.

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

Cause or Origin. Oxides of nitrogen are produced by burning and by the detonation and burning of explosives. They are also emitted from the exhaust of diesel engines. In the presence of electrical arcs or sparks, nitrogen in the air combines with oxygen (oxidizes) to form oxides of nitrogen.

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

Detection Methods. To test for nitrogen dioxide, you can use a nitrogen dioxide detector, a multi-gas detector, or chemical analysis.

Hold portable detectors low when you test for these relatively heavy gases. Their characteristic reddish-brown color may be another indication that there is nitrogen dioxide present.

When to Test. Test for oxides of nitrogen following a fire or explosion and after the detonation of explosives. Since diesel exhaust is a source of these gases, test in areas where diesel equipment is used.

Meaning of Findings. High NO_2 readings could indicate there has been a fire or that explosives are burning. Malfunctioning electrical equipment producing arcs or sparks could also be the source. If diesel equipment is causing the elevated NO_2 readings, that indicates ventilation is inadequate.

Hydrogen (H_2)

Specific Gravity. 0.0695

Explosive Range and Flammability. Hydrogen is a highly explosive gas. Air containing 4 to 74.2 percent hydrogen will explode even when there is as little as 5 percent oxygen present. Very violent explosions are possible when air contains more than 7 to 8 percent hydrogen. The presence of small quantities of hydrogen greatly increases the explosive range of other gases.

Health Hazards. At high concentrations, hydrogen can replace oxygen in the air and act as an asphyxiant. The most hazardous aspect of hydrogen, however, is the fact that it is highly explosive.

Solubility. Not soluble in water.

Color/Odor/Taste. Colorless, odorless, and tasteless.

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

Where Found. You can expect to find hydrogen in the vicinity of battery charging stations, where explosives have been detonated, and after explosions. Hydrogen may also be detected during firefighting when either water or foam extinguishing methods are used. You can also expect to find hydrogen in an area that's been sealed to extinguish a fire. Because hydrogen is relatively light, it tends to collect in high places.

Detection Methods. Hydrogen can be detected with a multi-gas detector, or by means of chemical analysis. Hold portable detectors high.

When to Test: Test for hydrogen after any fire or explosion and near battery charging stations in the mine. Also test for it when water, water mists, or foam is used to fight fires.

Meaning of Findings. The presence of hydrogen could indicate that a fire or explosion has taken place. Firefighting with water or foam could also be producing the hydrogen. Elevated readings could also indicate that there is inadequate ventilation around battery charging stations.

Hydrogen Sulfide (H_2S)

Specific Gravity. 1.1906

Explosive Range and Flammability. Hydrogen sulfide is flammable and explosive in concentrations from 4.3 to 45.5 percent in normal air. It is most explosive at 14.2 percent.

Health Hazards. Hydrogen sulfide is one of the most poisonous gases known. In low concentrations (.005 to .010 percent), hydrogen sulfide causes inflammation of the eyes and respiratory tract. Slightly higher concentrations (.02 to .07 percent) can lead to bronchitis or pneumonia. Higher concentrations (.07 to .10 percent) can cause rapid unconsciousness, cessation of respiration, and death. And .10 to .20 percent or more can cause rapid death.

Solubility. Soluble in water.

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

Cause or Origin. Hydrogen sulfide is produced when sulfur compounds decompose. It is found in certain oil and gas fields and in some gypsum mines. It also may be liberated from methane feeders in mines with methane.

Hydrogen sulfide is often liberated when acid mine water corrodes metallic sulfides. It can also be released from mine water which contains the gas in solution. Heating sulfides in the presence of moisture (as in mine fires) may also produce the gas. Blasting in sulfide ores can also liberate hydrogen sulfide.

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

Detection Methods. You can test for hydrogen sulfide with a hydrogen sulfide detector, a multi-gas detector, and by chemical analysis. Because H_2S is relatively heavy, hold your portable detector low when testing for this gas. You may recognize H_2S by its distinctive "rotten egg" odor. However, continued exposure to the gas will dull your sense of smell, so this may not always be a reliable detection method. Eye irritation is another indication that hydrogen sulfide is present.

When to Test: Test for hydrogen sulfide in poorly ventilated areas of the mine, during unsealing operations, and following mine fires.

Meaning of Findings. A buildup of hydrogen sulfide could indicate that ventilation is inadequate. It may also be produced by seepage from an oil or gas well. The presence of hydrogen sulfide might also indicate that excess water is accumulating in sealed or inaccessible areas of the mine.

Sulfur Dioxide (SO_2)

Specific Gravity. 2.2638

Explosive Range and Flammability. Will not burn or explode.

Health Hazards. Sulfur dioxide is a very toxic, irritating gas that is dangerous even in small concentrations; as little as 0.04 to 0.05 percent is dangerous to life. Even very tiny amounts of sulfur dioxide (.001 percent or less) will irritate your eyes and respiratory tract. Larger concentrations can cause severe lung damage and may cause respiratory paralysis and the complete inability to breathe.

Solubility. Highly soluble in water. (Sulfur dioxide is one of the most soluble gases found in mines.)

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

Cause or Origin. Sulfur dioxide may be produced by blasting in sulfide ores and by fires containing iron pyrite (commonly known as "fool's gold"). Sulfur dioxide may be released during the burning of some diesel fuels and by sulfide ore dust explosions.

Where Found. Because it is relatively heavy, sulfur dioxide tends to collect in low places in the mine and near sumps. You can expect to find it after some fires or explosions.

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

Detection Methods. You may test for sulfur dioxide by means of a multi-gas detector or by chemical analysis. Because sulfur dioxide is a relatively heavy gas, hold portable detectors low when you test for it.
Sulfur dioxide's distinctive odor and taste, and the respiratory tract and eye irritation you'll experience when exposed to it are also reliable indicators of its presence.

When to Test. Because it's highly soluble in water, test for sulfur dioxide when stagnant water is disturbed. Test for this gas following fires or explosions, and when sealed areas of the mine are opened after mine fires.

Meaning of Findings. High SO_2 readings could indicate a mine fire or a sulfide ore dust explosion.

Heavy Hydrocarbons

Ethane (C_2H_6) Propane (C_3H_8) Butane (C_4H_{10})

Specific Gravity.

Ethane 1.0493 –
Propane 1.5625 –
Butane 2.0100

Explosive Range and Flammability.

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

Health Hazards. These gases are not toxic. At high concentrations they can displace enough oxygen to cause death by asphyxiation, but you'll rarely find them in such high concentrations in mines.

Solubility. All three are slightly soluble in water.

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

Cause or Origin. After mine fires, small concentrations of these gases are often detected along with methane in mines that have methane. They also sometimes leak from gas or oil wells.
Where Found. The heavy hydrocarbons are often found in mines adjacent to oil or gas wells. Because they are heavy, these gases collect in low areas of the mine.

Detection Methods. You can detect ethane, propane, and butane with a portable detector or by chemical analysis. Because these gases are relatively heavy, hold your portable detector low when you test for them.

When to Test. Test for these gases following fires or explosions when methane is present. You should also test for the heavy hydrocarbons if oil or gas casings are accidentally entered during mining operations.

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

Acetylene (C_2H_2)

NOTE: For some mines, acetylene will not be a potential problem. Therefore, teach this material only if necessary.

Specific Gravity. 0.9107

Explosive Range and Flammability. Acetylene is combustible but it will not support combustion. Its explosive range in normal air is 2.5 to 80 percent.

Health Hazards. Acetylene is slightly toxic. In high concentrations, it can cause asphyxiation by depleting the oxygen in the atmosphere.

Solubility. Very slightly soluble in water.

Color/Odor/Taste. Acetylene is colorless and tasteless. It has a slight garlic odor.

Cause or Origin. Acetylene is formed when methane is burned or heated in air having low oxygen content.

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

Detection Methods. Test for acetylene with a multi-gas detector or by chemical analysis. You may also recognize it by its characteristic garlic odor. Since acetylene's specific gravity is near that of normal air, hold portable detectors at chest level.

When to Test. Test for acetylene after a methane explosion in air that is oxygen deficient.

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

Radon (Rn)

Specific Gravity. 7.526

Explosive Range and Flammability. Nonexplosive and nonflammable.

Health Hazards. Radon is not toxic. However, radon and radon daughters—a decay product of radon—are radioactive and emit radiation. Continued exposure to high levels of these gases has been linked to the incidence of lung cancer. Mines are required to keep exposure to radiation below 4 WLM (Working Level Months) per year. The exposure for any one month is limited to one WLM.

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

Solubility. Radon is highly soluble in water.

Color/Odor/Taste. Colorless, odorless, tasteless.

Cause or Origin. Radon is a gaseous decay product of the uranium series and is found in all uranium mines. It can also be liberated, but to a lesser extent, from almost any rock or soil. As radon is liberated into a mine atmosphere, it continues to decay and forms airborne particles the size of atoms called radon daughters.

Radon daughters are particularly dangerous. They adhere to respirable dust, and can be inhaled with the dust. Once inhaled, they become deposited in the lungs where they continue to decay, giving off radiation and damaging lung tissue. Radiation can also be absorbed by the skin. If the radiation hazard in an area is very high, breathing protection and protective clothing may be required.

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

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

When to Test. Regular tests are required in uranium mines. Tests should be made when ventilation is disrupted and when opening a sealed area.

Meaning of Findings. Excessive readings would indicate a disruption of ventilation.

Smoke, Rock-Strata Gases, and the Damps

Smoke

Smoke is a result of combustion. It consists of tiny particles of solid and liquid matter suspended in the air. The particles in smoke are usually soot or carbon, and tar-like substances such as hydrocarbons.

Although smoke may irritate your lungs when you inhale it, it is not normally considered to be an asphyxiant. However, smoke usually contains carbon monoxide and other toxic or asphyxiating gases produced by fires. This is why it is so dangerous to inhale smoke.

Also, if there is a sufficient amount of hydrocarbons in the smoke, the hydrocarbons can make the smoke explosive.

Besides the dangers involved in inhaling smoke and its potential for explosion, smoke is also hazardous in another important way: The presence of smoke limits your visibility. This single factor adds an extra element of difficulty to any rescue or recovery operation.

NOTE: Smoke from burning conveyor belts or cable insulation **also contains toxic substances** produced by the decomposition of Neoprene. These are **very toxic when inhaled.** For more information on these gases, refer to **Module 5 – *Fires, Firefighting, and Explosions*.**

Rock-Strata Gases

Rock-strata gases occur in some metal mining districts in the United States, particularly in Colorado and Nevada. Commonly called rock gas, it is assumed to be largely nitrogen and carbon dioxide, and is released from the rock strata under the influence of atmospheric pressures.

Because rock gas is largely nitrogen and carbon dioxide, the effect of rock gas is to produce an oxygen-deficient atmosphere. This can cause a person to suffocate if breathing protection is not worn.

The Damps

“Damps” are the names early miners gave to mixtures of gases. Many of these terms are still in use today. These names often describe what causes the mixtures or how they affect miners. **NOTE:** The word “damp” comes from the German word “dampf,” which means “vapors or gases.”

The damps most commonly found in mines are:

Whitedamp. Whitedamp is a mixture of carbon monoxide and air which results from a mine fire. It gets the name “whitedamp” from the fact that it is found in high concentrations in black powder smoke, which is white. The carbon monoxide in this mixture makes it toxic.

Stinkdamp. This is a mixture of hydrogen sulfide and air. Stinkdamp gets its name from the characteristic “rotten egg” odor of hydrogen sulfide. It is highly toxic and in certain concentrations it can be explosive.

Afterdamp. This is a mixture of carbon monoxide, carbon dioxide, methane, oxygen, nitrogen, and hydrogen. It is called “afterdamp” because it’s usually found after a mine fire or explosion. Afterdamp is toxic to breathe, and it may also be oxygen-deficient. Carbon monoxide is the most poisonous of the gases in afterdamp.

Blackdamp. Blackdamp gets its name from the fact that this mixture caused miners’ lights to go out. It is actually a mixture of carbon dioxide, nitrogen, and air. Blackdamp is produced by methane fires and explosions, so it also probably contains carbon monoxide. This mixture is oxygen-deficient so it makes breathing difficult, and can cause suffocation.

Firedamp. This is a mixture of methane and air that will burn or explode when ignited. The “fire” in firedamp comes from the fact that the mixture is flammable.

Review Questions: Ask the team members the following questions and allow time for them to answer. Discuss the correct answers with them so they fully understand the material covered in this section.

1. What are the five main causes of oxygen deficiency in the mine:

   Answer:
   1) insufficient or improper ventilation which fails to bring enough oxygen to the work area,
   2) displacement of the air's oxygen by other gases,
   3) a fire or explosion that consumes oxygen,
   4) the absorption of oxygen by coal, particularly at freshly cut faces, and
   5) consumption of oxygen by workers.

2. What are the explosive gases that may occur in the mine or mines you may be called to work in?

   Answer:
   1) Carbon monoxide 12.5 to 74.2%
   2) Hydrogen 4.0 to 74.2% even with as little as 5% oxygen present
   3) Hydrogen sulfide 4.3 to 45.5%
   4) Methane 5 to 15% in at least 12.1% oxygen
   5) Ethane 3.0 to 12.5%
   6) Propane 2.12 to 9.35%
   7) Butane 1.86 to 8.41%
   8) Acetylene 2.5 to 80%

   NOTE: Discuss the explosive ranges of the gases that are a problem at **the mine or mines your team will be serving.**

3. Name the gases that can be detected by color, odor, or taste, and explain these identifying features.

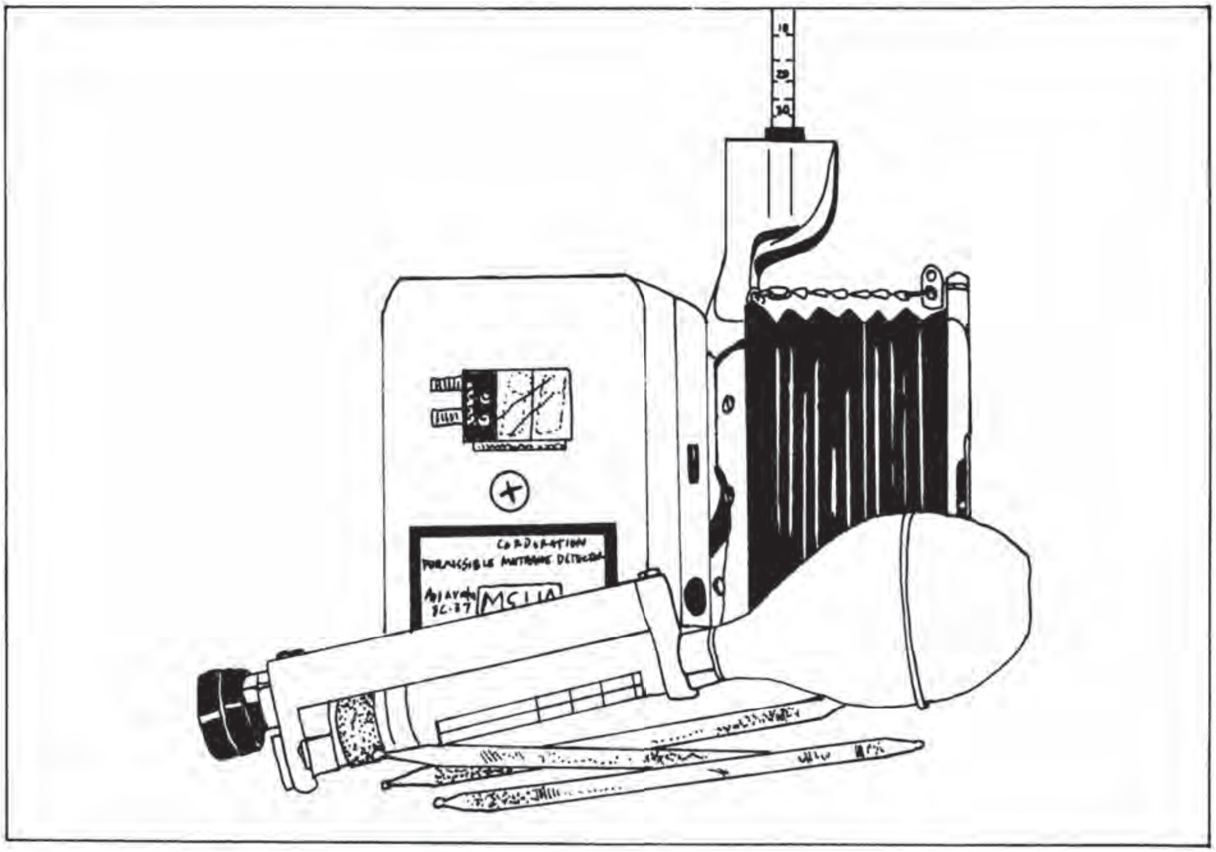
   Answer:
   1) Carbon dioxide—acid taste in high concentrations.
   2) Nitrogen dioxide—reddish brown in higher concentrations, odor and taste of blasting powder fumes.
   3) Hydrogen sulfide—rotten egg odor (however, continued exposure deadens your sense of smell), slight sweetish taste.
   4) Sulfur dioxide—sulfur odor, acid taste.
   5) Propane and butane—"gassy" odor in certain concentrations.
   6) Acetylene—slight garlic odor.

4. Of the gases we've talked about, which ones are toxic if you inhale them?

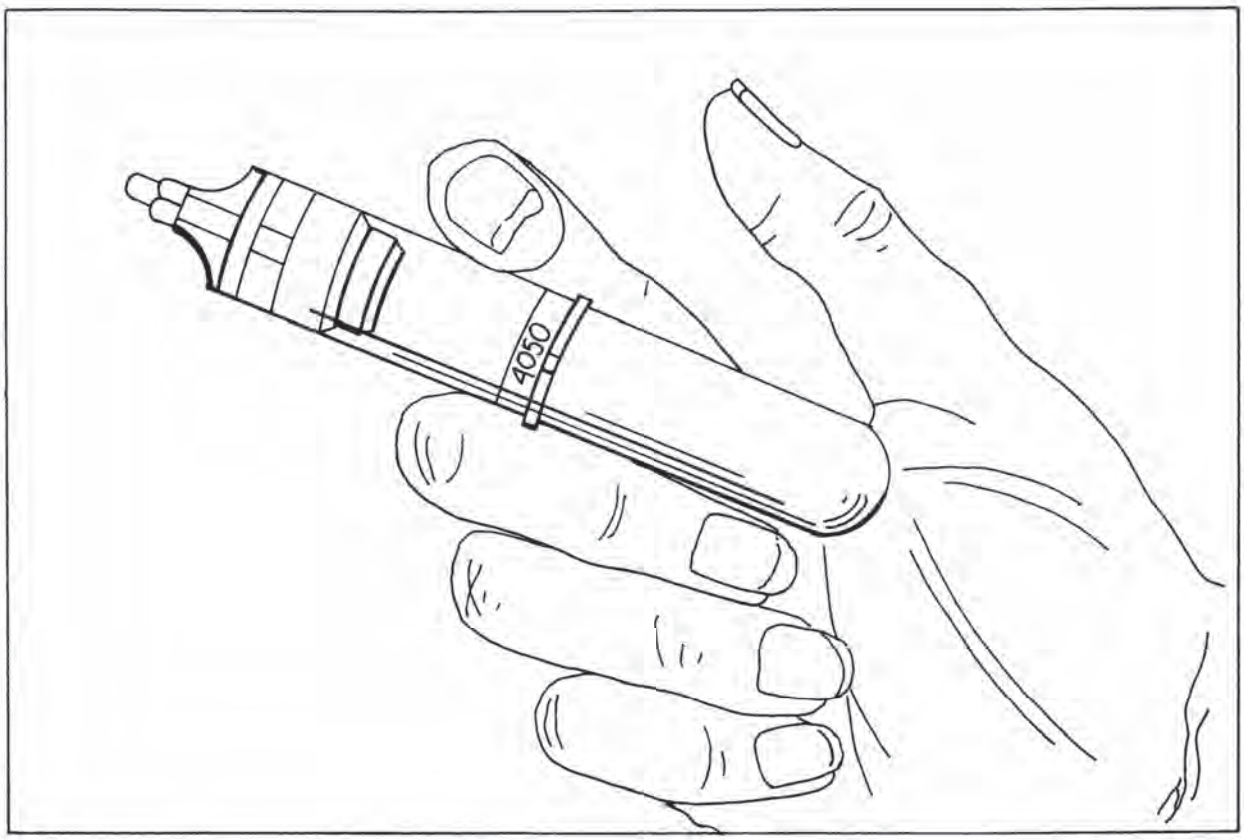
   Answer:
   Carbon monoxide, oxides of nitrogen, hydrogen sulfide, sulfur dioxide, and acetylene.

5. What are the five major damps? Explain what each mixture contains and why it's dangerous.

Answer:
1) Whitedamp—carbon monoxide and air. Toxic.
2) Stinkdamp—hydrogen sulfide and air. Toxic, and may be explosive.
3) Afterdamp—carbon monoxide, carbon dioxide, methane, oxygen, nitrogen, and hydrogen. Toxic, explosive, and can be oxygen-deficient.
4) Blackdamp—carbon dioxide, nitrogen, and air. Oxygen-deficient. Can cause suffocation.
5) Firedamp—methane (5 to 15%) and air. Can explode.



Visual 1 **Gas Detectors**



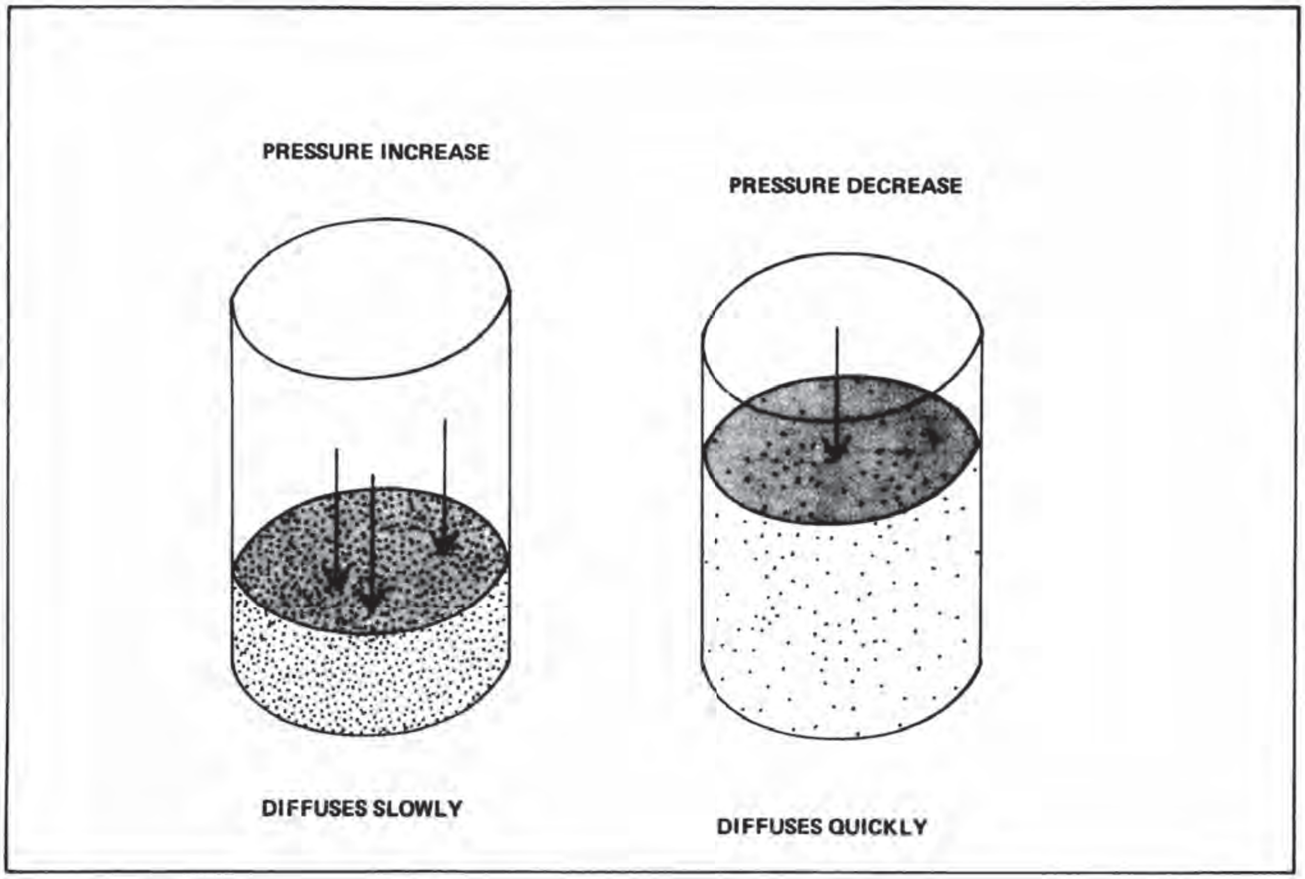
Visual 2 **Syringe for Gas Samples**

Effects of Temperature and Pressure

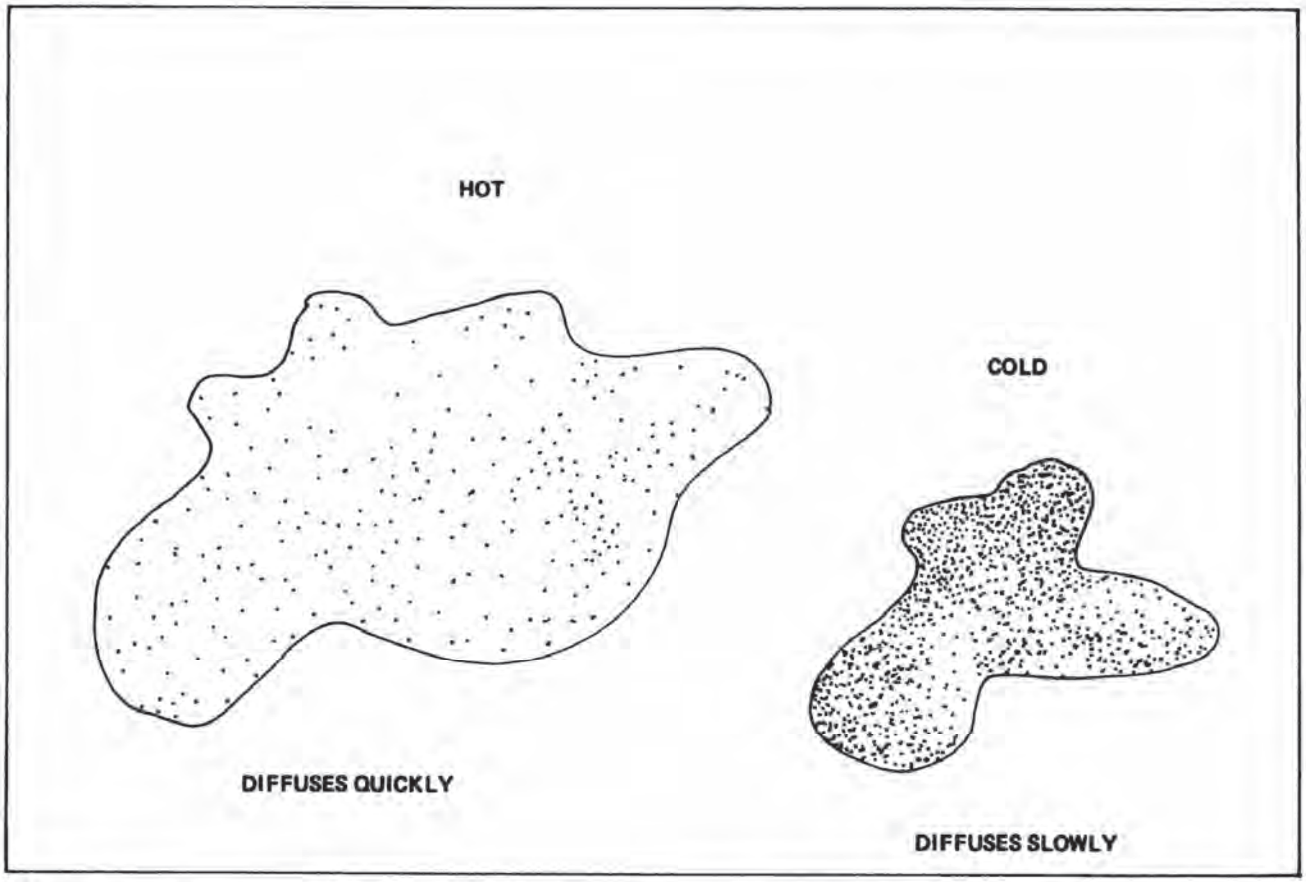
Pressure increases – gas contracts
Pressure decreases – gas expands

Temperature increases – gas expands
Temperature decreases – gas contracts

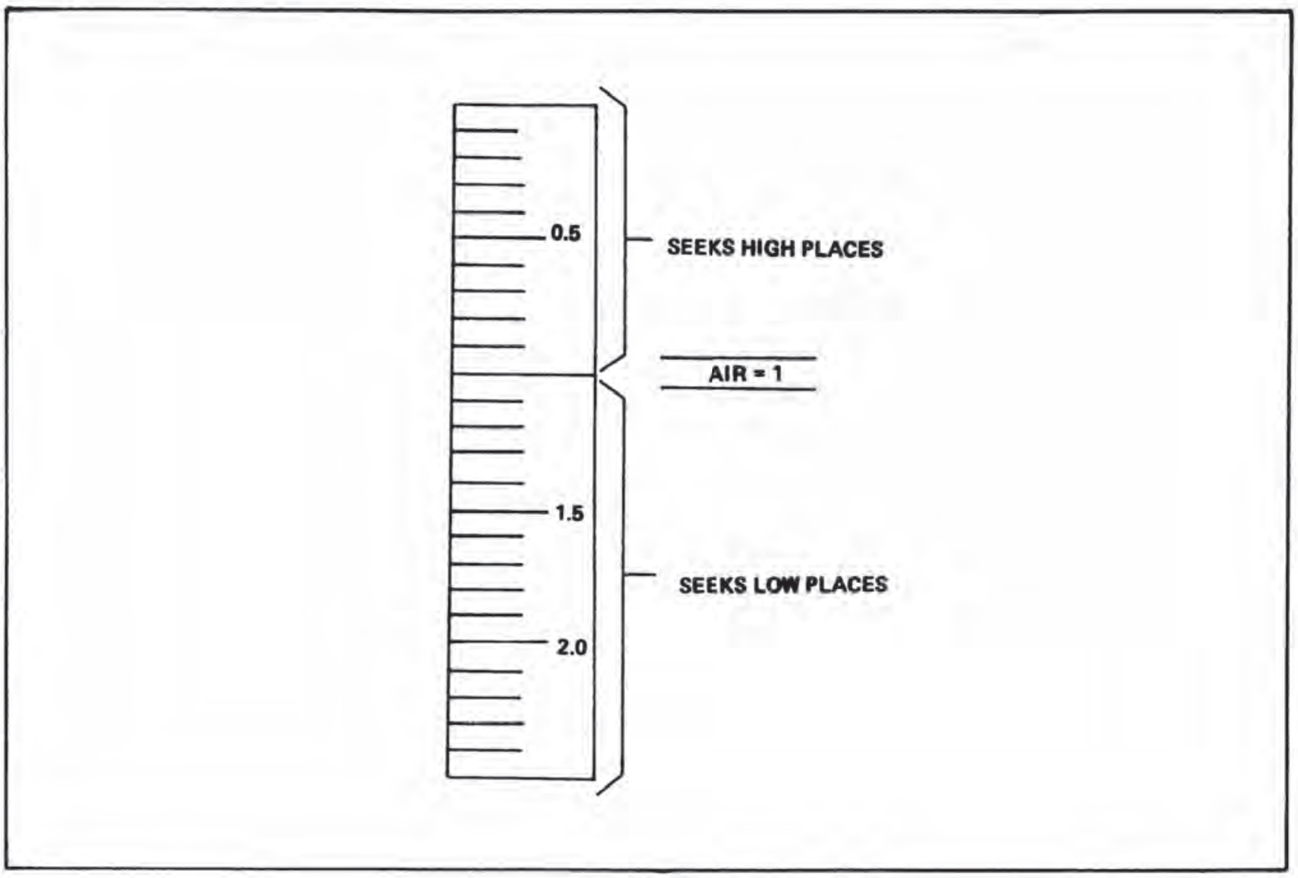
Visual 3 **Effects of Temperature and Pressure on Gas**



Visual 4 **Effects of Pressure on Gas**



Visual 5 **Effects of Temperature on Gas**

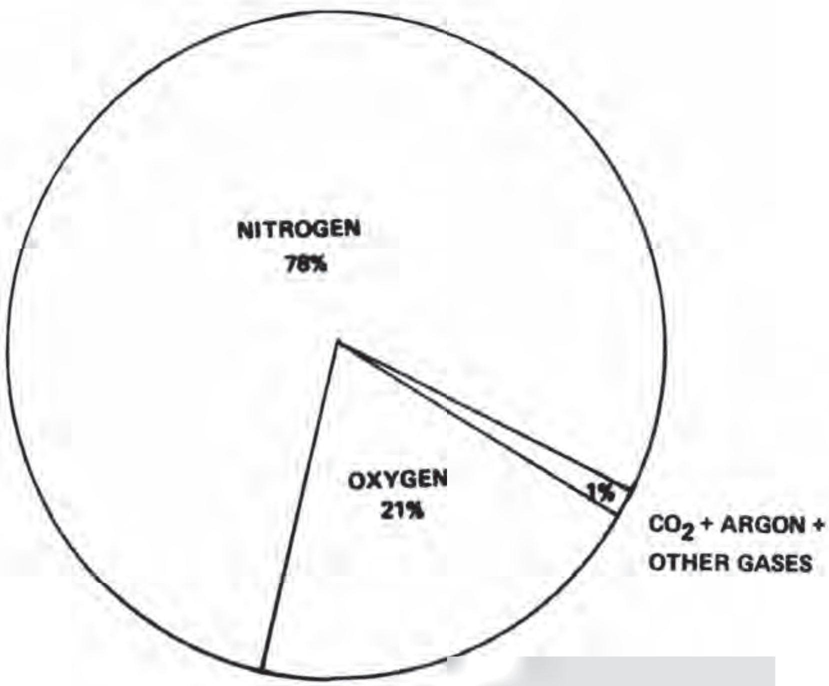


Visual 6 **Specific Gravity (Relative Weight)**

EFFECTS OF TOXIC GAS DEPEND ON :

1. CONCENTRATION
2. TOXICITY
3. LENGTH OF EXPOSURE

Visual 7 **Effects of Toxic Gas**



Visual 8 **Contents of Normal Air**

Gas	Chemical Symbol	Specific Gravity	Explosive Range	Health Hazards	Solubility	Color	Odor	Taste
Air	– –	1.000	– –		– –	– –	– –	– –
Oxygen	O_2	1.1054	Supports combustion	Oxygen deficiency: 17% panting, 15% dizziness and headache, 9% unconsciousness, 6% death.	Moderate	– –	– –	– –
Nitrogen	N_2	0.9674	– –	Asphyxiant (oxygen depletion).	Slight	– –	– –	– –
Carbon Dioxide	CO_2	1.5291	– –	Increases breathing rate. May cause death in high concentration.	Soluble	– –	– –	Acid in high concentrations
Carbon Monoxide	CO	0.9672	12.5 to 74.2%	Highly toxic. Can be an asphyxiant.	Slight	– –	– –	– –
Nitrogen Dioxide	NO_2 N_2O_4	1.5894	– –	Highly toxic. Corrosive effect on lungs. May be asphyxiant.	Only slight	Reddish brown	Blasting powder fumes	Blasting powder fumes
Hydrogen	H_2	0.0695	4.0 to 74.2% Highly explosive	Asphyxiant (oxygen depletion).	– –	– –	– –	– –
Hydrogen Sulfide	H_2S	1.1906	4.3 to 45.5%	Highly toxic. Can be an asphyxiant.	Soluble	– –	Rotten eggs	Sweetish
Sulfur Dioxide	SO_2	2.2638	– –	Highly toxic. Can be an asphyxiant.	Highly	– –	Sulfurous	Acid (bitter)
Methane	CH_4	0.5545	5 to 15%	Asphyxiant (rare).	Slight	– –	– –	– –
Ethane	C_2H_6	1.0493	3.0 to 12.5%	Asphyxiant (rare).	Slight	– –	– –	– –
Propane	C_3H_8	1.5625	2.12 to 9.35%	Asphyxiant (rare).	Slight	– –	"Gassy" in high concentrations	– –
Butane	C_4H_{10}	2.0100	1.86 to 8.41%	Asphyxiant (rare).	Slight	– –	"Gassy" in high concentrations	– –
Acetylene	C_2H_2	0.9107	2.5 to 80%	Only slightly toxic. Asphyxiant (rare).	Only slight	– –	– –	Garlic
Radon	Rn	7.526	– –	Exposure to radiation.	Highly	– –	– –	– –

Visual 9 **Mine Gas Chart**

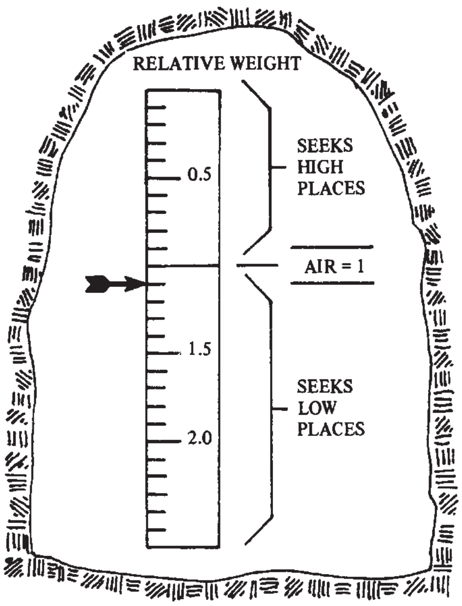
Gas	Detection Methods	When to Test
Oxygen (O_2)	Oxygen indicator. Chemical analysis.	During any team exploration.
Nitrogen (N_2)	Chemical analysis.	When an oxygen deficient atmosphere is suspected. In mines where nitrogen issues from rock strata. In inactive areas where ventilation has been inadequate.
Carbon Dioxide (CO_2)	Carbon dioxide detector. Multi-gas detector. Chemical analysis.	After a fire or explosion. When entering abandoned areas. When reopening sealed areas.
Carbon Monoxide (CO)	Carbon monoxide detector. Multi-gas detector. Chemical analysis.	During any team exploration, especially when fire is suspected.
Nitrogen Dioxide (NO_2)	Nitrogen dioxide detector. Multi-gas detector. Chemical analysis. Color.	After mine fires or explosions. When diesel equipment is used. After detonation of explosives.
Hydrogen (H_2)	Multi-gas detector. Chemical analysis.	After mine fire or explosion. Near battery-charging stations. When steam is produced by water, mist, or foam in fire-fighting.
Hydrogen Sulfide (H_2S)	Hydrogen sulfide detector. Multi-gas detector. Chemical analysis. Eye irritation.	In poorly ventilated areas. During unsealing operations. Following mine fires.
Sulfur Dioxide (SO_2)	Multi-gas detector. Chemical analysis. Odor, taste, and respiratory tract irritation.	When standing water is disturbed. After mine fires or explosions and when reopening sealed areas of the mine after mine fires.
Methane (CH_4)	Methane detector. Chemical analysis.	During any team exploration. When normal ventilation is disrupted. When entering abandoned workings.
Heavy Hydrocarbons Ethane (C_2H_6) Butane (C_3H_8) Propane (C_4H_{10})	Multi-gas detector. Chemical analysis.	Following fires or explosions when methane is present. Following accidental entry into adjacent oil or gas well casings.
Acetylene (C_2H_2)	Multi-gas detector. Chemical analysis. Odor.	Following a methane explosion in air which is low in oxygen.
Radon (Rn)	Survey meter.	When normal ventilation is disrupted and during unsealing operations.

Visual 10 Gas Detection Chart

Oxygen (O_2)

SPECIFIC GRAVITY: 0.1054

EXPLOSIVE RANGE: Supports combustion



OTHER PROPERTIES

Color: None

Odor: None

Taste: None

CAUSE

Air contains 21% oxygen. Oxygen is necessary for life. Oxygen deficiency is caused by humans breathing in confined spaces, insufficient ventilation, displacement by other gases, or consumption by fire or explosion.

HEALTH HAZARDS

Oxygen Deficiency:
- 17% – panting
- 15% – tightness in forehead, headaches, dizziness
- 9% – unconsciousness
- 6% – death

DETECTION

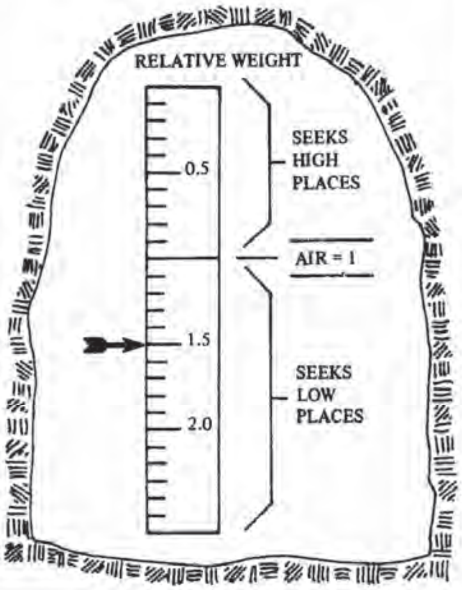
Use either oxygen indicator or chemical analysis.
Hold portable detectors at waist height. Test for oxygen deficiency as often as necessary during team exploration.

Visual 11 **Oxygen Chart**

Carbon Dioxide (CO_2)

SPECIFIC GRAVITY: 1.5291

EXPLOSIVE RANGE: Not explosive



OTHER PROPERTIES

Color: None

Odor: None

Taste: High concentrations can produce an acid taste

CAUSE

CO_2 is normal component of air. Product of complete combustion. Is also produced:

1. By oxidation.
2. By decaying timbers.
3. As a by-product of breathing.
4. During fires, explosions, and blasting.

HEALTH HAZARDS

In high concentrations, CO_2 increases breathing rate. Can cause death.

DETECTION

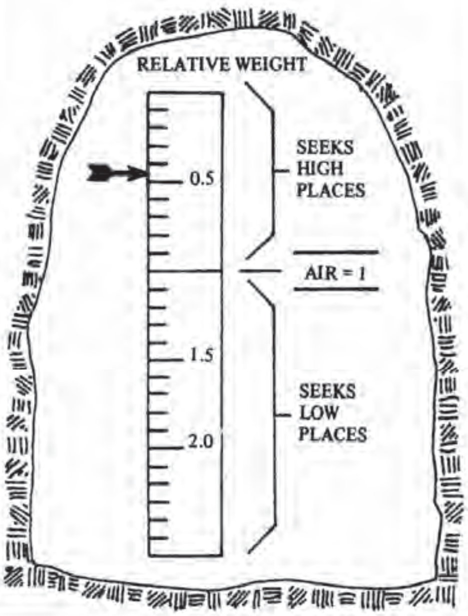
Use carbon dioxide detector, multi-gas detector, or chemical analysis. Hold detector low. Test after a fire or explosion and when entering an inactive area of the mine or reopening a sealed area.

Visual 12 **Carbon Dioxide Chart**

Methane (CH_4)

SPECIFIC GRAVITY: 0.5545

EXPLOSIVE RANGE: 5 to 15% in air containing at least 12.1% oxygen



OTHER PROPERTIES

- Color: None
- Odor: None
- Taste: None

CAUSE

Can be liberated:

1. From the strata when carbonaceous shale is penetrated.
2. Occasionally when carbonaceous rock is contacted or in vicinity.
3. From feeders or some clay veins.
4. By the decomposition of timbers.
5. When water is removed from mine.

HEALTH HAZARDS

Nontoxic. May cause asphyxiation at high concentrations.

Most dangerous aspect is the fact that it's explosive.

DETECTION

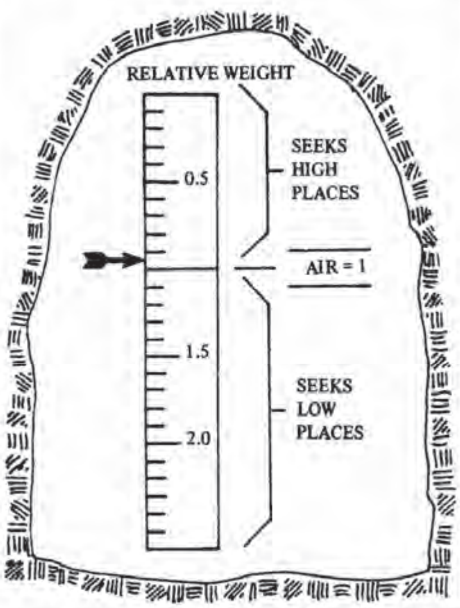
Use methane detector or chemical analysis. Hold portable detectors high. Test as often as necessary during team exploration. Test when normal ventilation is disrupted and when entering abandoned workings.

Visual 13 **Methane Chart**

Carbon Monoxide (CO)

SPECIFIC GRAVITY: 0.9672

EXPLOSIVE RANGE: 12.5 to 74.2 percent in normal air



OTHER PROPERTIES

- Color: None
- Odor: None
- Taste: None

CAUSE

Produced by incomplete combustion of carbon materials. Produced by mine fires and explosions, burning or detonation of explosives, and internal combustion engines.

HEALTH HAZARDS

Extremely toxic even in low concentrations. Interferes with oxygen-carrying capacity of blood. First symptom: tightening across fore-head. Effects cumulative over time. If exposed to high concentration, you experience few symptoms before losing consciousness.

DETECTION

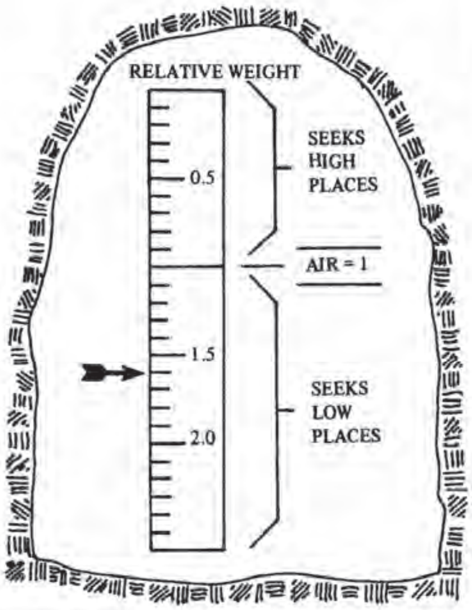
Can be detected by means of CO detector, multi-gas detector, chemical analysis. Hold detector at chest level. Test as often as necessary during team exploration, especially if fire is suspected.

Visual 14 **Carbon Monoxide Chart**

Nitrogen Dioxide (NO_2)

SPECIFIC GRAVITY: 1.5894

EXPLOSIVE RANGE: Not explosive



OTHER PROPERTIES

Color: Reddish brown

Odor: Blasting powder fumes

Taste: Blasting powder fumes

CAUSE

Can be produced:

1. By burning.
2. By detonation and burning of explosives.
3. By diesel engines.
4. In the presence of electrical arcs or sparks, nitrogen in the air combines with oxygen (oxidizes) to form oxides of nitrogen.

HEALTH HAZARDS

Very toxic, even small amounts will irritate throat. Mixes with moisture in lungs to form acids that corrode respiratory passages and cause them to swell. Exposure to .01 to .015% is dangerous. Exposure to .02 to .07% can be fatal.

DETECTION

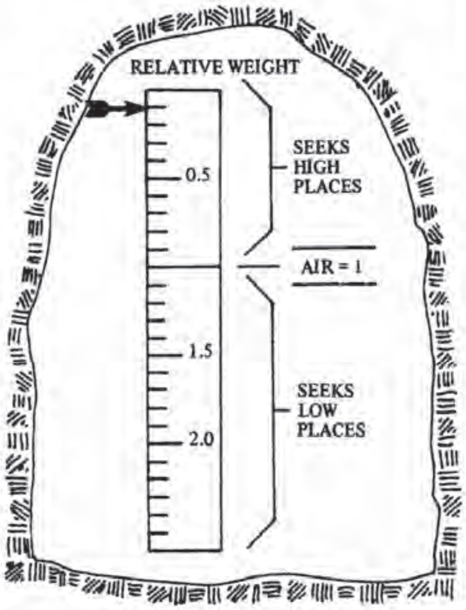
Nitrogen dioxide detector, multi-gas detector, chemical analysis, color. Hold detectors low. Test following a fire or explosion and after the detonation of explosives. Test in areas where diesel equipment is found.

Visual 15 **Nitrogen Dioxide Chart**

Hydrogen (H_2)

SPECIFIC GRAVITY: 0.0695

EXPLOSIVE RANGE: 4.0 to 74.2% in air with as little as 5% oxygen



OTHER PROPERTIES

Color: None

Odor: None

Taste: None

CAUSE

Can be produced:

1. By incomplete combustion of carbon materials during fires and explosions.
2. When water or steam comes in contact with hot carbon materials during firefighting.
3. During battery charging.

HEALTH HAZARDS

At high concentrations, hydrogen can replace oxygen in the air and act as an asphyxiant. Also, hydrogen is highly explosive.

DETECTION

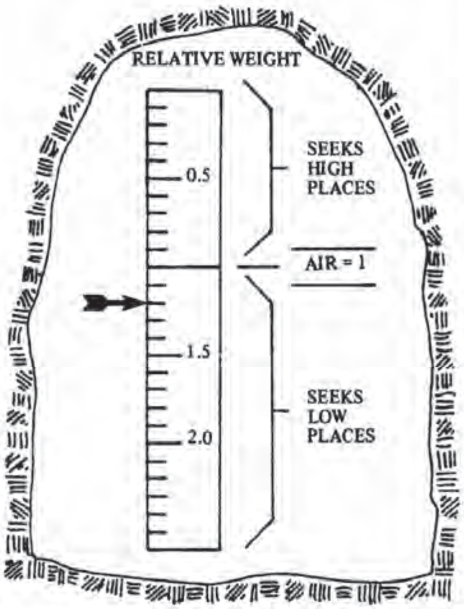
Use multi-gas detector or chemical analysis. Hold detector high. Test after any fire or explosion and near battery-charging stations. Also test when water, water mists, or foam are used to fight fires.

Visual 16 **Hydrogen Chart**

Hydrogen Sulfide (H_2S)

SPECIFIC GRAVITY: 1.1906

EXPLOSIVE RANGE: 4.3 to 45.5% in normal air



OTHER PROPERTIES

Color: None

Odor: Rotten eggs

Taste: Slight sweetish taste

CAUSE

Produced when sulfur compounds decompose. Found in certain oil and gas fields and in some gypsum mines. Can be liberated:

1. From methane feeders.
2. When acid mine water corrodes metallic sulfides.
3. From mine water that contains the gas in solution.
4. When sulfides are heated in the presence of moisture.
5. When sulfide ores are blasted.

HEALTH HAZARDS

Extremely poisonous. .005 to .010% causes inflammation of eyes and respiratory tract. .02 to .07% can lead to bronchitis or pneumonia. .07 to .10% can cause rapid unconsciousness, cessation of respiration, and death. .10 to .20% or more can cause rapid death.

DETECTION

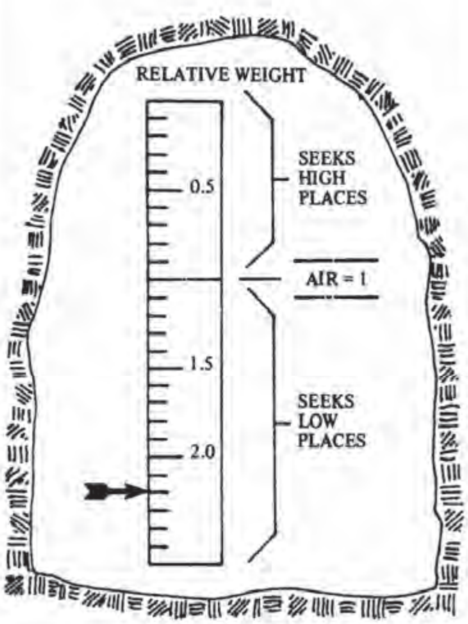
Use hydrogen sulfide detector, multi-gas detector, or chemical analysis. Hold detector low. Test in poorly ventilated areas of mine during unsealing operations, and following mine fires.

Visual 17 **Hydrogen Sulfide Chart**

Sulfur Dioxide (SO_2)

SPECIFIC GRAVITY: 2.2638

EXPLOSIVE RANGE: Will not burn or explode



OTHER PROPERTIES

Color: None

Odor: Sulfurous

Taste: Bitter, acid

CAUSE

Can be produced:

1. By blasting in sulfide ores and by fires containing iron pyrite.
2. During the burning of some diesel fuels.
3. By sulfide ore dust explosions.

HEALTH HAZARDS

Very toxic, dangerous in even small concentrations.

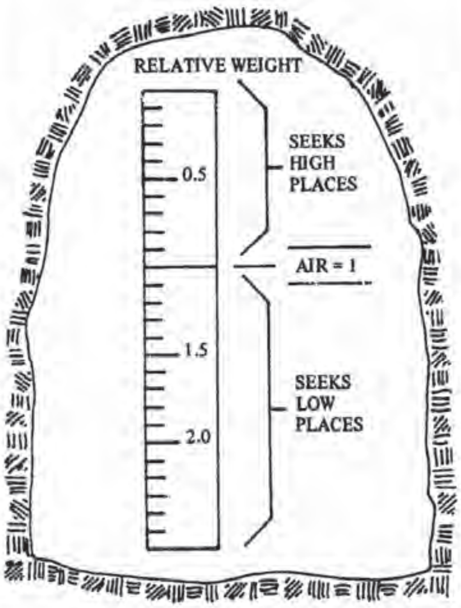
DETECTION

Use multi-gas detector or chemical analysis. Test in low places and near sumps, following fires or explosions and during unsealing operations. Also, because it's highly soluble in water, test when stagnant water is disturbed.

Visual 18 **Sulfur Dioxide Chart**

SPECIFIC GRAVITY:

EXPLOSIVE RANGE:



OTHER PROPERTIES
Color:
Odor:
Taste:

CAUSE

HEALTH HAZARDS

DETECTION

Visual 19 **Fill-in Chart**

General Review

Mine Gases

Choose the correct answer to each of the following questions.

1. Normal air contains approximately what percent oxygen?
   a. 15%
   b. 21%
   c. 31%
   d. 79%

2. The explosive range of a methane/air mixture (normally 5-15%) will change if:
   a. certain other combustible gases are present.
   b. coal dust is suspended in the atmosphere.
   c. there is less than 12.1% oxygen in the atmosphere.
   d. all of the above.

3. Carbon monoxide is:
   a. a gas found in all mining operations
   b. a normal constituent of air
   c. detected during a mine fire or explosion
   d. a product of the breathing process

4. An elevated concentration of carbon dioxide in mine air can be harmful because:
   a. it is highly explosive
   b. it increases the breathing rate
   c. it is highly toxic in small concentrations
   d. all of the above

5. An elevated concentration of nitrogen in mine air can be harmful because:
   a. it can lower the oxygen content of the air
   b. it is highly explosive
   c. it is highly toxic
   d. all of the above

6. Oxides of nitrogen can occur in a mine atmosphere:
   a. when certain explosives are used
   b. when diesel-powered equipment is being used
   c. when electric equipment produces arcs or sparks
   d. all of the above

7. Accumulations of hydrogen in the mine atmosphere are dangerous because hydrogen:
   a. is highly toxic
   b. is highly soluble in water
   c. is highly explosive
   d. gives off a suffocating odor

8. Characteristics of hydrogen sulfide include:
   a. explosive
   b. highly toxic
   c. can be liberated from pools of stagnant water
   d. all of the above

9. Which of the following is not true of sulfur dioxide?
   a. it is explosive
   b. it is highly toxic
   c. it is highly soluble in water
   d. it can occur during mine fires

10. The most likely source of ethane, propane, or butane in a mine is:
   a. use of diesel equipment
   b. battery charging stations
   c. leakage from adjacent gas or oil wells
   d. all of the above

11. Acetylene would normally be found in a mine atmosphere where:
   a. diesel equipment is used
   b. methane has burned or exploded in air with a lowered oxygen content
   c. leakage has occurred from adjacent oil or gas wells
   d. battery charging stations are located

12. Match each damp with its components:

1. Firedamp	a. Carbon monoxide and air
2. Blackdamp	b. Hydrogen sulfide and air
3. Afterdamp	c. Carbon dioxide, nitrogen, and air
4. Whitedamp	Carbon monoxide, carbon dioxide, methane, oxygen, nitrogen, and hydrogen
5. Stinkdamp	e. Methane and air

13. Mine rescue teams are required by Federal law to have available:
   a. one detecting device for every gas listed as dangerous by the U. S. Bureau of Mines
   b. one detecting device for each gas normally encountered in the mine(s) the team serves
   c. four detecting devices for each gas normally encountered in the mine(s) the team serves
   d. one detecting device for each [illegible]ber

14. Atmospheric pressure and temperature are important factors because they:
    a. affect the rate of diffusion of a gas by ventilation
    b. can cause false readings on gas detection instruments
    c. lower oxygen content in the mine
    d. all of the above

15. Two gases that are highly soluble in water are:
    a. methane and acetylene
    b. hydrogen sulfide and hydrogen
    c. nitrogen and sulfur dioxide
    d. hydrogen sulfide and sulfur dioxide

16. A gas that is normally found near the roof or in high places in the mine is said to have a low:
    a. level of toxicity
    b. level of explosivity
    c. specific gravity
    d. level of solubility

17. The amount of coal dust suspended in the mine atmosphere is most important because:
    a. it can alter the explosive range of methane.
    b. it can affect the specific gravity of oxygen.
    c. hydrogen is liberated from the coal dust.
    d. coal dust lowers the oxygen content in the mine atmosphere.

18. A nontoxic gas can still be dangerous because it can:
    a. displace oxygen
    b. burn
    c. explode
    d. all of the above

19. The type of coal mine where the greatest amount of methane would be likely to be found would be a:
    a. drift mine with tight and compact adjoining strata
    b. drift mine with loose or broken adjoining strata
    c. shaft mine with tight and compact adjoining strata
    d. shaft mine with loose or broken adjoining strata

20. Gases that are neither toxic nor explosive:
    a. are not found in mine atmospheres
    b. are not dangerous
    c. can be dangerous because they can displace oxygen
    d. cannot be detected with today's detection instruments

General review answers:

1. b
2. d
3. c
4. b
5. a
6. d
7. c
8. d
9. a
10. c
11. b
12. (1) e
    (2) c
    (3) d
    (4) a
    (5) b
13. c
14. a
15. d
16. c
17. a
18. d
19. c
20. c

Glossary

Adsorption – Physical adhesion of molecules to the surfaces of solids without chemical reaction.

Asphyxiate – To suffocate or choke.

Atmospheric pressure – Force exerted by air. Atmospheric pressure is measured on a barometer.

Blower – A gas feeder under high pressure which causes the gas to issue at considerable velocity.

Casing – Piping used to support sides of a borehole and to prevent entry of loose rock, gas, or liquid.

Combustible – Capable of burning; flammable.

Contaminant – Something which fouls or impurifies.

Corrode – To eat away gradually.

Damps – Descriptive names given by miners to identify mixtures of gases.

Diffuse – To scatter, spread out, or blend.

Disperse – To scatter or get rid of; to dispel.

Explosive range – The range of concentrations within which a gas will explode if ignited (expressed in percentages).

Feeder – Small cracks through which methane or other gas escapes from coal.

Flammable – Burnable.

Ignite – To set on fire.

Inundation – The state of being flooded.

Methane outburst – Sudden emission of methane from coal seam or surrounding rock.

Mine atmosphere – The air in an underground mine.

Oxidize – To cause to combine with oxygen.

Poison – Substance which destroys lif

PPM – Parts per million.

Smoke – Tiny particles of solid and liquid matter suspended in air.

Solubility – Ability to dissolve in water.

Specific gravity – The weight of a gas compared to an equal volume of air under the same temperature and pressure.

Sulfur – A nonmetallic element which exists either free or in combination with other elements. It often occurs as pyritic sulfur, commonly known as "fool's gold."

TLV (Threshold Limit Value) – Used to denote the average concentrations of gases to which workers can (under Federal regulations) be exposed over an 8-hour daily period.

Toxic – Poisonous.

Vacuum bottle – Container used to collect gas samples for chemical analysis.