Abandoned and Inactive Mine Safety Training – Underground Mine Hazards
National Park Service Geologic Resources Division – August 2003

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(This paper is available at http://www2.nature.nps.gov/grd/distland/about_aml.htm)

WHY INVESTIGATE ABANDONED AND INACTIVE MINE WORKINGS?

Geologists often have reason to enter abandoned mines. Mineral examiners conduct underground inspections in assessing mineral resource values for mining claim validity and patent examinations. Exploration geologists inspect inactive mine workings to assess further development potential.

Wildlife biologists conduct surveys of underground mine workings to assess critical wildlife habitat. For instance, abandoned mines have become increasingly important to the survival of numerous sensitive and protected bat species since increased urban development, deforestation, and exploitation of caves threaten their natural habitat. Although external surveys can be used to gain useful information, underground surveys are best for assessing the importance of habitat provided by abandoned mines. Information from underground surveys is often essential in determining the most appropriate type of closure for a particular mine opening.

Cultural resource specialists are interested in abandoned mines and related artifacts that may be left underground.

Limited funding and time force abandoned mine land (AML) reclamation programs to prioritize closures. By entering abandoned underground workings, the true hazard level can be evaluated to determine which sites should be prioritized for closure. It is also often necessary to enter an abandoned mine in order to design and implement a suitable closure.

Because members of the public **will** enter abandoned mines, it is incumbent on land managers to know what hazards are being left exposed to the public until appropriate closures can be constructed, and to take whatever temporary measures are possible and necessary to minimize the hazard.

In the event that a rescue may be required, it is good to have an idea of the extent and layout of underground workings before entering an abandoned mine. It is wise, therefore, for qualified specialists to map underground mine workings. The maps not only help in rescue situations, but also assist geologists, biologists, and cultural resource specialists in conducting their assessments.

WHO IS QUALIFIED TO ENTER ABANDONED UNDERGROUND MINES?

The Mine Safety and Health Administration (MSHA) discourages entry into abandoned mines, except for rescue situations conducted by an authorized mine rescue team. MSHA is the agency in the Department of Labor that regulates and periodically inspects safety in active mining operations. Their official policy is that no one, despite experience, should be allowed to enter unventilated areas deeper than 100', unless they are trained and equipped as part of an emergency mine rescue team. MSHA, however, has no regulatory authority concerning abandoned mines.

It is the policy of the Office of Surface Mining Reclamation and Enforcement (OSMRE, or just OSM), as handed down to its state programs, to forbid entry of underground workings in excess of 25', or any deeper than is required to construct a suitable closure for each opening. All federal funding for abandoned mine closure and reclamation is currently disbursed to 26 individual state and 3 Native American tribal programs through OSM. Outside of its own programs, however, OSM has no regulatory authority over the policies of other agencies or entities concerning abandoned mines.

Local state mine inspectors do have jurisdiction concerning abandoned mines. In many states it is against the law to enter abandoned mines. State mine inspectors may exercise their authority over federal employees on federal lands. Strictness of the laws and the level of enforcement varies from state to state.

Federal land management agencies are responsible for developing their own safety policies concerning abandoned mines. As much as possible, these policies should be consistent with MSHA, OSM, and state regulations. The USDA Forest Service (**USDAFS**) policy was most recently addressed in a memorandum dated April 6, 1999, from the Director of Minerals and Geology Management to all Regional Foresters. USDAFS requires "non-certified" employees to be accompanied by Federal or State mine inspectors or by certified mineral examiners who are qualified by their Regional Director for the Minerals Program. The US Bureau of Land Management (**BLM**) most recently addressed mine safety in a draft policy issued by the Director in an Instruction Memorandum dated April 18, 2001. BLM's plan is in conformance with their confined space policy as based on OSHA regulations at 29 CFR 1910.146, with modifications stipulated in the Instruction Memorandum. BLM's policy is also covered under BLM Manual Handbook 1112-2, §3.8 and §27.5. USDAFS and BLM both offer annual 1-week Mine Safety Workshops for all employees whose job requires them to work in and around abandoned mines.[1] These classes are open to other agencies and government contractors pending available space. To date the National Park Service (**NPS**) has not established an underground mine entry policy, although it has worked closely with USDAFS and BLM in establishing AML policy and training NPS personnel for underground safety. **The NPS Geologic Resources Division does not sanction entry of abandoned underground mines by NPS personnel without underground AML training and experience unless they are accompanied and supervised by someone with that background.**

[1] See http://www.ntc.blm.gov/ (602-906-5604) and http://www.fs.fed.us/r1/minerals/NMTO/NMTO.htm (406-329-3626) for more information.

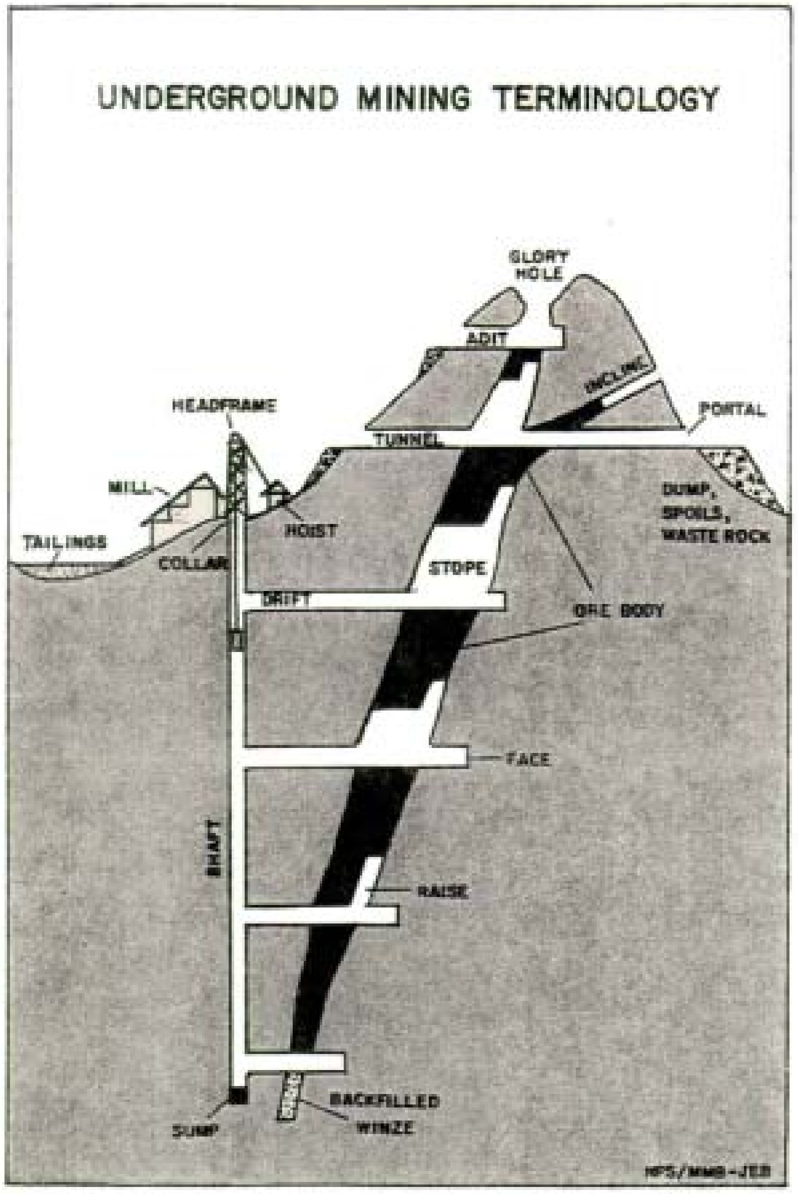

Figure 1. **MINING TERMINOLOGY**

A. FALLING HAZARDS

1. **Shafts, Winzes, Raises -** Shafts are vertical or declined openings exposed on the ground's surface, whereas winzes and raises are declined or inclined openings (respectively) underground inside of a mine. The area around the top of these openings is called the "collar." One of the primary dangers of vertical openings is when the collar has deteriorated through weathering and wear. Loose rock around a collar, which slopes gradually into a shaft, creates a slipping hazard that can draw its victim into the shaft. Inside a mine, raises and winzes often connect between different levels. An explorer with inadequate lighting could easily walk into a winze left open in the floor. Rotten boards or plywood may also conceal a winze or shaft, and should never be trusted. Always check under any covering in a mined area that looks like it could conceal a vertical opening. Falls could result in a serious injury or death by the following means:

   - Impact on the walls or at the bottom of the shaft during a fall
   - The shaft may be a trap for contaminated or oxygen-deficient air, so that the victim who survives the fall may be asphyxiated.
   - The shaft may be flooded at depth, which presents the possibility of drowning.
   - The victim may be unable to climb out, especially if injured. When unaccompanied in a remote situation, a minor injury could be fatal.

2. **Glory Holes -** Many underground mines will follow a mineralized area upward near or to the ground's surface. When underground workings reach or collapse to the surface in this manner, a glory hole is the result. Quite often, the caved area underground is much larger than the hole at the surface, causing the glory hole to collapse and enlarge through time. If you are standing at the edge of a glory hole, chances are good that the ground you are standing on is undercut and subject to collapse.

3. **Stopes -** Underground stopes are large, often irregular mine openings where an entire zone of mineralization has been excavated. The larger the stope, the less stable it is. Stopes may reach the ground's surface ("open stope") or may connect between levels in a mine. With inadequate lighting inside the mine, a person may fall into a stope to a lower level. Loose rock may fall from overhead stopes at any time.

4. **Collapse Zones –** Shallow underground mines are subject to subsidence or collapse at any time. Be particularly aware of surface depressions around mine sites. Avoid walking in these areas, and see if they may correlate to mapped underground workings in the area.

5. **Cave-ins -** Unlike caves, mines are artificial, temporary openings designed to last as long as it takes to extract the ore. When a mine is abandoned, there is no longer a maintenance program to address deteriorating rock conditions and weakened ground supports. Caves are formed over thousands of years by relatively stable processes, whereas mines are created by blasting, which destabilizes the rock left in place. Soft, stratified rock types such as shale

tend to collapse easily, but often in small pieces. Harder, more massive rock types such as granite, limestone, or sandstone collapse less frequently, but often more catastrophically in large blocks. Keep in mind that mines often follow fault zones, which are inherently unstable. Cave-ins may be the result of:

a. **Unstable Rock - The first way to assess rock stability is to look at the floor of the mine.** If the floor is covered with loose rock, the mine is most likely unstable. If the floor is clean, rock conditions are most likely (but not necessarily) stable. Stratified or severely jointed rock types are most prone to collapse under the forces of gravity, or from the force of "overburden" (pressure exerted by overlying rock). An area that is "taking weight" may make creaking and popping noises, and sometimes rock under stress can be seen to shoot off in splinters. Timbers under stress are also prone to splintering and emitting creaking noises. Other signs of weight stress are crushed timbers and bent steel support beams.

b. **Decayed Timbers -** Through time, timbers that once supported the rock above will oxidize and rot. Although they may remain in-place and appear to provide support, they could be totally ineffective.

c. **Ineffective Rock Bolts -** Rock bolts are used to stabilize weak areas in a mine. Sometimes an abandoned mine may have entire areas where numerous bolts are found dangling several feet below the roof. In these areas, the rock that these bolts once supported has since collapsed.

6. **Unsafe Structures and Ladders -** Due to rotting and desiccation, wooden headframes, platforms, ladders, etc. become weak and unstable. They should not be trusted to support your weight.

7. **Pools of Water** - Standing water may conceal flooded lower levels of a mine, boards with rusty nails, debris, etc. Upon entering an abandoned mine, inspectors should probe any standing water in front of them with a bar or stick before proceeding. Assume that mine water is toxic and unsuitable for drinking.

8. **Highwalls and Steep Pit Walls –** These features are briefly mentioned in this discussion of underground mine hazards because surface and underground features are often both found at individual mine sites. A "highwall" is the vertical (or near-vertical) exposure of an open cut on its uphill side. Open pits typically have extremely steep walls on all sides that are usually "benched" with roadways to provide access to the bottom of the pit. Any steep rock wall exposed by blasting will tend toward instability through time, especially in a surface location where the rock is fully exposed to the forces of weathering. As with shaft collars, erosion near the edges may lead to a decayed, loose surface that increases the possibility of slipping and falling over the edge.

B. EXPLOSIVES

It is not uncommon to find explosives in abandoned mines. **Under <u>no</u> circumstances should explosives be handled or touched by anyone other than a certified blaster.** When explosives are found, any distinguishing markings or characteristics should be noted, such as the form of the explosive and any printing on cases or on the explosives themselves. In particular, note any dates marked on explosives or their packaging, as age of an explosive is useful in determining its probable composition and stability. If there is any doubt whether the material in question is an explosive, assume that it is. The appropriate authorities should be notified and a certified blaster should be contacted to arrange for disposal.

Powder is the miner's term for explosives. Miners will often store their supply of explosives at the end of an inactive drift, or in a small side room off of a main drift in the mine, called the **powder magazine**. Since explosives and blasting caps should be stored separately, there may also be a separate **cap magazine**. Explosives are also often stored in a separate cache away the rest of the mine.

Underground mine development is advanced by drilling specific patterns of holes in the **face** of a drift, loading these holes with explosives, blasting, and **mucking** (removing) the resulting broken rock. Each drill / blast / muck cycle is called a **round**. In a surface pit the mine is advanced by drilling and blasting a series of vertical holes in a **bench**, accounting for the tiered, or stair-step appearance common to all open pit mines.

Explosives come in many varieties, some of which are listed below:

1. **Stick Dynamite -** Dynamite is produced in various sizes, but basically looks like a paper-wrapped mixture of packed moist sawdust or powder. It may vary typically from 6 inches to 2 feet in length, from ½ to 1½ inches in diameter, and is usually packed in 50-pound cases. If the sticks appear wet or have clear golden beads of moisture on the surface, this is most likely nitroglycerine which has "bled" out of the dynamite. Bleeding occurs with age or when dynamite is heated. Nitroglycerine is the primary explosive component of dynamite and is highly unstable and dangerous when separated from the matrix of the dynamite stick.

2. **Water Gels -** Water gels are similar in shape and packaging to stick dynamite, but have a plastic wrapper enclosing a jelly-like or creamy mixture in any variety of colors.

3. **ANFO-Prill -** Prill typically comes in 50-pound bags and looks like fertilizer. It is often white, but may come in a variety of colors depending on the manufacturer. The acronym, "ANFO" stands for <u>a</u>mmonium <u>n</u>itrate and <u>f</u>uel <u>o</u>il, its principle components. This combination makes for an extremely effective, yet economical blasting agent, and is more stable than dynamite. It is therefore the blasting agent of

choice in many of today's larger mines. Rather than being placed in blast holes by hand, it is typically blown and compacted into drill holes using compressed air.

4. **Boosters -** Boosters in underground mining typically look like plastic tubing which fits over the end of a blasting cap. In open pit mines where large-diameter holes (often 3 inches to 6 inches) are drilled and blasted, boosters may appear more like a molded plug wrapped in paper or encased in plastic with one or more holes through it to affix it to a detonator. The combination of a detonator connected to a booster is referred to as a **primer**. Boosters are typically used in conjunction with prill, which requires more energy than dynamite to initiate detonation.

5. **Detonator Cord -** "Det cord" is usually a brightly-colored braided hard nylon cord with a white powder core of pentaerythritetetranitrate (PETN). PETN is highly explosive, and consequently, det cord burns at rates of up to 20,000 feet per second. It is used to connect explosive charges together.

6. **Detonators -** Detonators, or **blasting caps**, are metallic cylinders about the size of a small cigarette with attached wires (electric caps), plastic tubing, or cord (non-electric caps). Fresh caps will be marked, usually with a small paper tag bearing a number that refers to the delay time between ignition of the fuse and actual detonation of the cap. Caps are timed so that drill holes can be blasted in a sequence that optimizes the efficiency of breaking and moving the rock. Blasting caps may be found in a storage cache, or, since they are easy to drop or misplace through carelessness, they can often be found laying about a mine site. The blasting agent in older caps was mercury fulminate. Today, the explosive charge in caps is typically PETN. Blasting caps are powerful enough to blow off a hand so they should be treated with the same respect as other explosives.

7. **Fuse -** Fuse with a blasting cap on one end is used in initiating (detonating) a non-electric blast. One of the more common fuses used is **blackwick**, which looks like a black waxy hollow-core cord. It burns at a rate of 1 foot per minute, so the length of a fuse determines the delay between "spitting" a round and the actual blast. If a miner needs 5 minutes after spitting a round to clear people out of the area of danger, he may, for instance, select an 8-foot fuse. After spitting the round at the face, he then clears the area (assisted by others if the mine has several branches that must be cleared) yelling, "Fire in the hole!" After clearing, he then posts himself as a guard at a safe distance from the blast, keeping others from entering the blast area. After the blast goes off, no one is allowed back into the blast area for 30 minutes. This allows any defective charges extra time to detonate (although this is not common), and allows time for the ventilation system to clear the air of gases generated by the blast.

8. **Spitter -** A spitter is used to initiate burning of a fuse. It looks like a small cardboard tube with a pull-cord, similar to a "party-popper." The spitter tube fits

over the end of a fuse, then its cord is pulled to initiate burning of the fuse. The charge in a spitter is very small, but could burn the skin if the cord is pulled when the end of the spitter is directed toward someone.

9. **Misfires -** Misfires are explosive charges that for some reason did not detonate with the rest of a blast. Miners check for misfires after each blast, but may overlook them. One indication of a possible misfire is an irregularity in the typical profile of a drift. For instance, if a given mine typically has an arched roof, but there is a protrusion of rock in the arch of one round, this would be a likely place to find a misfire. This irregular protrusion may, however, just be a **bootleg**: a drill hole where explosives were not packed tightly, and when detonated, they simply blew out of the hole instead of breaking the surrounding rock. When entering a mine, an inspector watches the **ribs** (sides), **back** (roof, or ceiling), and faces (ends) of all drifts for irregularities and potential misfires. If wires, tubing, fuse cord, or dynamite can be seen protruding from a drill hole, it should be treated as a misfire. Misfires must be blasted in-place by a certified blaster. **No attempt should be made to touch a misfire or to remove it from the hole.**

C. **DISORIENTATION -** In larger mines, it is easy to become disoriented. This can be quite unsettling and may lead to panic. In a panic situation, all of the other underground hazards become that much more dangerous. Some investigators will use "string line" measuring devices in mapping underground workings or simply to measure distance into the mine. Remnant string line is very handy for finding one's way back out of a complex mine.

D. **WILDLIFE -** An abandoned mine may be home for many animals such as snakes, rodents, bats, or larger mammals. Animals that are normally reclusive and passive may become aggressive if backed into a corner of an abandoned mine by inquisitive intruders. Animal droppings can harbor diseases such as Hantavirus or Histoplasmosis. Every effort should be made to avoid disturbing wildlife underground and to avoid stirring up dust in the area of animal droppings. A respirator should be used if dust is generated in an underground survey, particularly if animal droppings are present.

Encounters with wildlife may be equally detrimental to the wildlife. For instance, abandoned mines often provide critical habitat to bats, which have an essential role in the ecosystem. Disturbing an underground **maternity roost** (a place where females bats give birth and nurture young) could cause adult bats to abandon their helpless young. Awakening bats in a **hibernaculum** (a place used for hibernation) could cause them to expend too much energy, leaving inadequate nutrition to sustain life through the remaining winter months when food sources such as insects are unavailable.

E. **HAZARDOUS MATERIALS** - Drums or other containers of unknown materials are often abandoned on a mine site or inside the mine itself. These containers should not be opened and should only be handled by a hazardous materials specialist. As with abandoned explosives, any distinguishing markings on containers should be noted and reported to the proper authorities.

F. MINE GASES – The composition of clean, dry air at sea level is 78.07% nitrogen, 20.95% oxygen, 0.93% argon, 0.03% carbon dioxide, and 0.01% other gases. Air composition can be altered in underground mines for a number of reasons. The most common mine gases, reasons for their generation, their physical properties, and the effects and symptoms of human exposure are summarized below:

1. **Oxygen (O_2) -** Oxygen deficiency (**Anoxia**) may result from combustion, blasting, oxidization of organic material (e.g., mine timbers, coal), respiration in confined spaces, or replacement by other gases. Oxygen is highly flammable in high concentrations, which are unlikely to be found underground except where leaky oxygen cylinders are stored.

Oxygen Content (% by Volume)	Threshold Limit Values (TLVs)*, Effects, and Symptoms[2] (at Atmospheric Pressure)
23.0 *	Upper permissible oxygen level
20.95	Typical ambient air conditions
19.5 *	Minimum permissible oxygen level
15 - 19	Decreased ability to work strenuously. May impair coordination and can induce early symptoms in persons with coronary, pulmonary, or circulatory problems.
12 - 15	Respiration increases in rate; pulse up; impaired coordination, perception, and judgement.
10 - 12	Respiration further increases in rate and depth; poor judgement; lips blue.
8 - 10	Mental failure; ashen face; blue lips; nausea; vomiting; fainting; unconsciousness.
6 - 8	8 minutes: 100% fatal 6 minutes: 50% fatal 4-5 minutes: recovery with treatment
4 - 6	Convulsions; coma in 40 seconds; respiration ceases; death.

*** The area should be evacuated at oxygen concentrations of 19.5% or less, or in concentrations above 23%.**

[2] Symptoms listed in this report vary with each individual's state of health and degree of physical activity.

2. **Carbon Monoxide (CO) -** Carbon monoxide is an odorless, tasteless, and colorless gas that may build up in a confined space, usually as a result of combustion, blasting, or heating of flammable substances. It can also be produced by certain coals at room temperature. CO is slightly lighter than air, so may tend to stratify toward the roof of a drift. CO inhibits the oxygen-carrying capacity of the blood by combining more readily with hemoglobin than oxygen. The rate at which CO combines with blood depends on the exposure time, CO concentration, and the activity of the exposed individual. CO builds up in the bloodstream with continuous exposure and may reside in the body for days or weeks after exposure, so the symptoms listed below are given as a function of concentration over time. In high concentrations of carbon monoxide, a person will collapse and become helpless with little or no warning.

ppm	%	TLV*, Effects, and Symptoms through Time
50 *	0.005	Permissible exposure level for 8 hours. Some agencies use the more conservative TLV of 35 ppm.
200	0.02	Slight headache and discomfort after 3 hours
400	0.04	Headache and discomfort after 2 hours
600	0.06	Headache and discomfort after 1 hour
1000-2000	0.1 – 0.2	Headache, discomfort, and slight heart palpitations after 30 minutes
1000-2000	0.1 – 0.2	Headache, discomfort, and tendency to stagger after 1.5 hours
1000-2000	0.1 – 0.2	Headache, discomfort, staggering, and nausea after 2 hours
2000-2500	0.2 – 0.25	Unconsciousness after 30 minutes
4000	0.4	Fatal in less than 1 hour

*** The area should be evacuated at carbon monoxide concentrations in excess of 50 ppm.**

3. **Methane (CH_4) -** Methane is the most common flammable gas in mines, but other hydrocarbons such as ethane and propane may also be present in trace amounts. While hydrocarbon gases are most often associated with coal mines, they may also be found in mines adjacent to oil and gas fields or in strata that contain combustible materials. Methane is odorless, tasteless, and colorless, and stratifies along the ceiling of a drift since it is much lighter than air. Although it is not toxic, it acts as an asphyxiant by diluting the oxygen concentration in air. Methane in air will ignite at a 5% concentration (by volume). This is termed the "lower explosive limit," or "100% **LEL**." Methane also has an upper explosive limit at 300% LEL (15% by volume in air). Above this level, methane has displaced so much oxygen that there is no longer adequate oxygen to support combustion. These properties of methane are diagramed below:

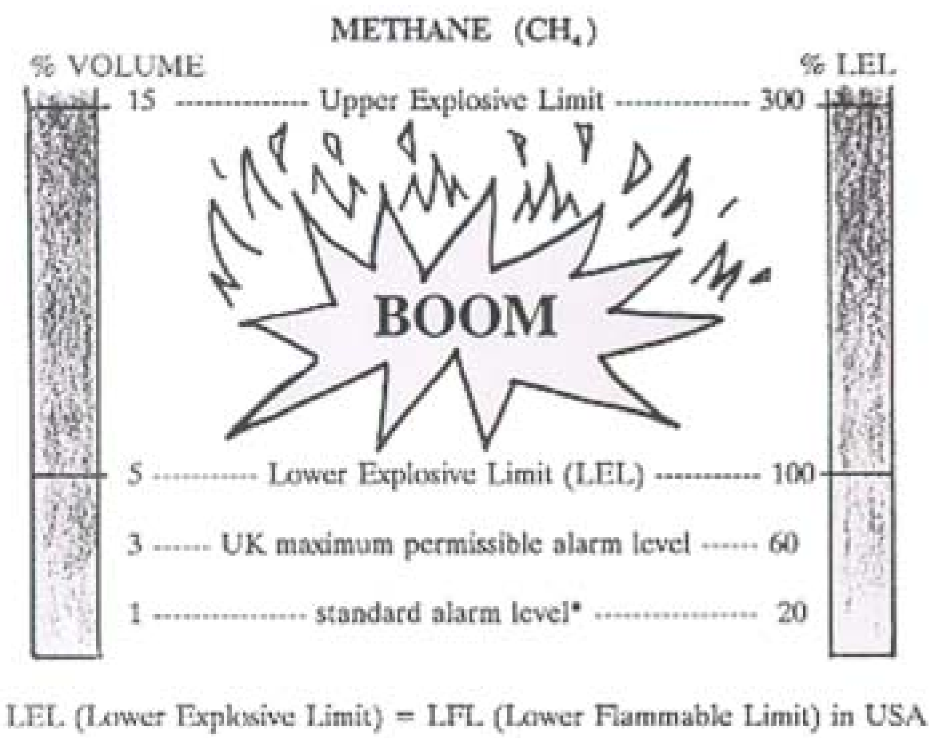

Figure 2. Upper and Lower Explosive Limits of Methane

*** The area should be evacuated at methane concentrations in excess of 20% LEL (1% by volume in air).**

4. Carbon Dioxide (CO_2) - Carbon dioxide is produced through respiration, combustion, and blasting, and it can exude naturally from coal seams, carbonate strata, and other rock types. It is colorless, much heavier than air, and has a slight acid taste when present in high concentrations. While carbon dioxide is commonly present in the air (0.03%), it is hazardous in higher concentrations. The following chart demonstrates some of its effects:

ppm	%	TLV*, Effects, and Symptoms
5,000	0.5*	Breathing (ventilation) is deeper and faster than normal.
30,000	3	Ventilation doubles
100,000	10	Tolerable only for several minutes at low activity. (Note: Due to air displacement, 10% CO_2 concentration reduces oxygen content to 18.9%.)

In typical respiration, humans breathe air at 20.95% O_2 and 0.03% CO_2 and exhale 16% O_2 and 4% CO_2 . In confined spaces, therefore, oxygen can quickly be replaced by carbon dioxide. Mining may intercept pressurized CO_2 -bearing strata. Being much heavier than air, CO_2 stratifies along the floor of a drift and low-lying areas, displacing the air. This is one reason why extreme caution, proper instrumentation, and approved procedures should be used when descending into a mine. When entering a mine on a steady downgrade, a person may not be aware of elevated CO_2 until his mouth reaches the CO_2 level. By walking into the area, however, the person has mixed the stratified gas with the good air above. The resulting mixture may be incapable of supporting respiration, and the person may not be able to evacuate the mine.

*** The area should be evacuated at carbon dioxide concentrations in excess of 5,000 ppm (0.5%).**

5. **Hydrogen Sulfide (H_2S) -** Hydrogen sulfide is a colorless, toxic, and flammable gas that can be formed when blasting in sulfide ores, or it may be formed in reducing environments such as areas of decaying timbers or where a large animal falls down a shaft, dies, and decays. Hydrogen sulfide is common in varying concentrations in many hydrocarbon deposits. Although its foul odor (like rotten eggs) is easily detected at low concentrations, it is not at higher concentrations because H_2S quickly desensitizes the olfactory nerves, leaving a person unaware of its presence. In high concentrations, a person may collapse with little or no warning. Hydrogen sulfide is heavier than air, so it tends to stratify in low areas.

ppm	%	TLV*, Effects, and Symptoms through Time
10*	0.0001*	Permissible exposure level for 8 hours
50 - 100	0.005 - 0.01	Mild eye and respiratory irritation after 1 hour
200 - 300	0.02 – 0.03	Marked eye and respiratory irritation after 1 hour
500 - 700	0.05 – 0.07	Unconscious and death after 30 minutes to 1 hour
> 1000	> 0.1	Unconscious and death within minutes

*** The area should be evacuated at hydrogen sulfide concentrations in excess of 10 ppm.**

6. **Sulfur Dioxide (SO_2) –** Sulfur dioxide is a highly toxic, colorless, suffocating, and irritating gas that smells like sulfur. It is much heavier than air, so stratifies along the floor of a mine when present. Sulfur dioxide is produced by fires in the presence of iron pyrite and by blasting in certain sulfide ores, and is more likely to be encountered in wet sulfide mines since it is highly soluble in water. Sulfur dioxide is **extremely** irritating to the respiratory system and is not commonly a problem because it is so noxious that no one would attempt to enter an area of significant contamination.

*** The area should be evacuated at sulfur dioxide concentrations in excess of 5 ppm.**

7. **Nitrogen (N) –** Nitrogen is the main dilutant of oxygen in air. In fact, it composes 78.08% of normal air by volume. Some rock types can generate nitrogen. It is colorless, odorless, tasteless gas that is slightly lighter than air. While nitrogen is not toxic, it is considered an asphyxiant because it replaces oxygen if introduced to air, producing an oxygen deficient atmosphere. Precautions for nitrogen are therefore the same as those for anoxia.

*** While nitrogen is not toxic, atmospheres in excess of 78.08% nitrogen are oxygen deficient.**

8. **Nitrogen Dioxide (NO_2) –** Oxides of nitrogen are common in the emissions from diesel and gasoline engines, and can also be generated by electrical discharges and blasting. They are toxic because they form corrosive acids when mixed with moisture in the lungs. NO_2 is the most toxic oxide of nitrogen, and has a TLV of 5 ppm. It is reddish-brown and heavier than air, so tends to stratify low. Nitrogen oxide (NO) may occur with nitrogen dioxide, and has a TLV of 25 ppm. Oxides of nitrogen are not usually a problem in abandoned mines because their mode of generation is from operations typical only of active mines.

*** The area should be evacuated at nitrogen oxide levels in excess of 25 ppm and nitrogen dioxide concentrations in excess of 5 ppm.**

9. **Hydrogen (H_2) –** Hydrogen is another gas that is possible, but unlikely to be encountered in an abandoned mine. It is typically only encountered after an explosion or fire, or near battery charging areas. Hydrogen is not toxic, but is considered an asphyxiant since it displaces air, leading to anoxic conditions. Because it is lighter than air, hydrogen stratifies toward the roof of a mine. It is colorless, odorless, and tasteless.

*** While hydrogen is not toxic, it can displace air in a closed environment, leading to anoxic conditions.**

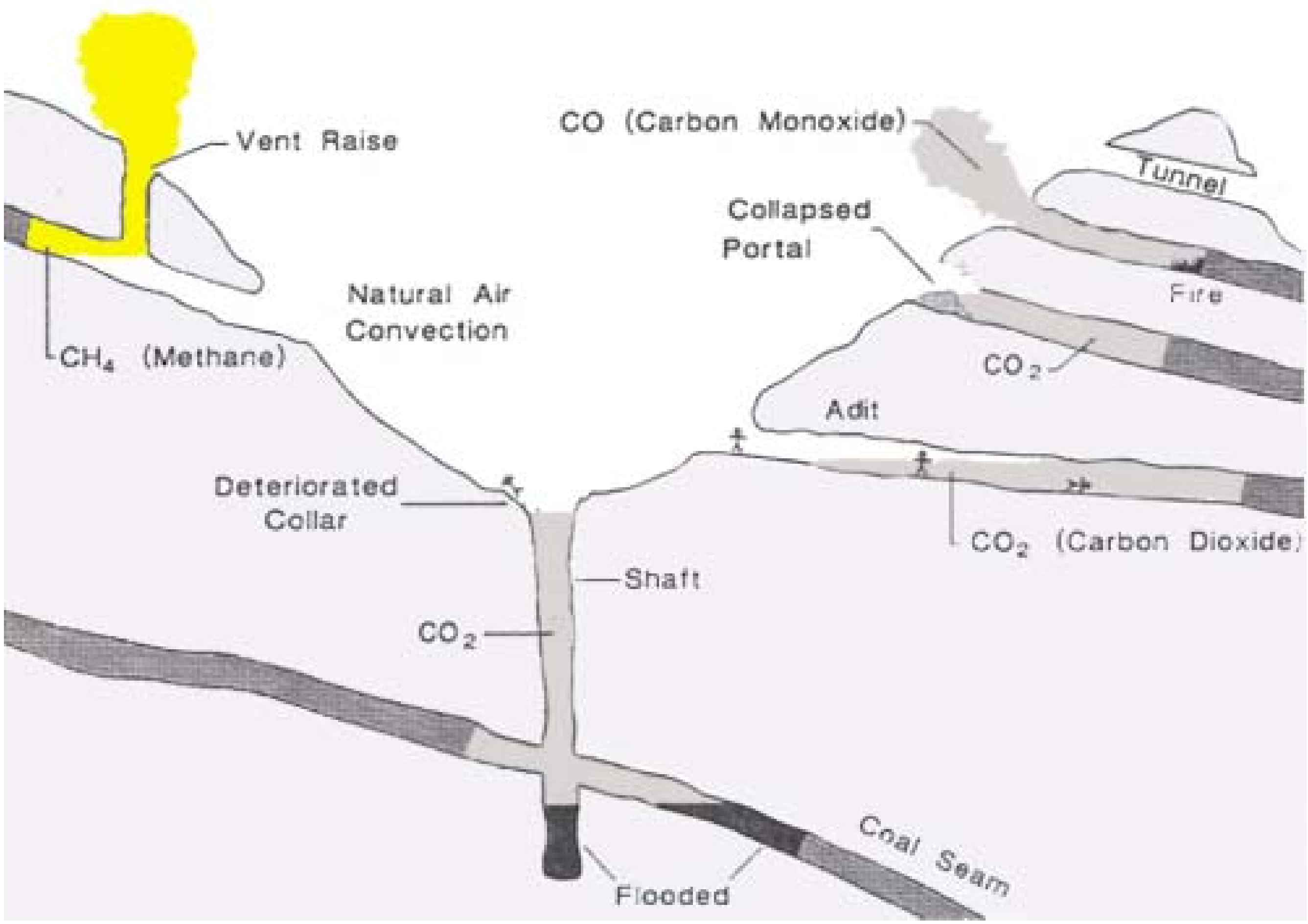

Figure 3. **Potential Underground Gas Hazards**

10. **Radon gas (Rn-222) and its progeny -** Radioactive elements contain an unstable configuration of protons and neutrons in their nuclei. For instance, uranium-238 (U238) will decay through time to lead-206 (Pb206) in a defined sequence of steps, as depicted in the Uranium-238 Decay Series chart (Figure 6). The U238 decay series accounts for most of the radiation typically encountered in nature. When an atom of a certain element "throws off" an **alpha (α) particle** (composed of 2 neutrons and 2 protons, with an atomic mass of 4) from its nucleus, it becomes a new element (**daughter**, or **progeny** in the plural form) with an atomic mass of 4 less than the original element (**parent**). (Atomic mass is the total number of neutrons and protons in an atom's nucleus.) Discharge of an alpha particle in this manner is called "alpha radiation." When the atomic nucleus discharges a **beta (β) particle** (an electron thrown off by a neutron as it decays into a proton), the atom becomes a new element of the same atomic mass, but different atomic number. (The atomic number is the total number of protons in the nucleus.) Discharge of beta particles is called "beta radiation." **Gamma (γ) rays** (non-particulate energy rays) may accompany either of these processes. The rate of radioactive decay, or degree of activity, is constant for each element, and is measured by its **half life:** the time it takes for half of the atoms of an element in a sample to undergo radioactive decay.

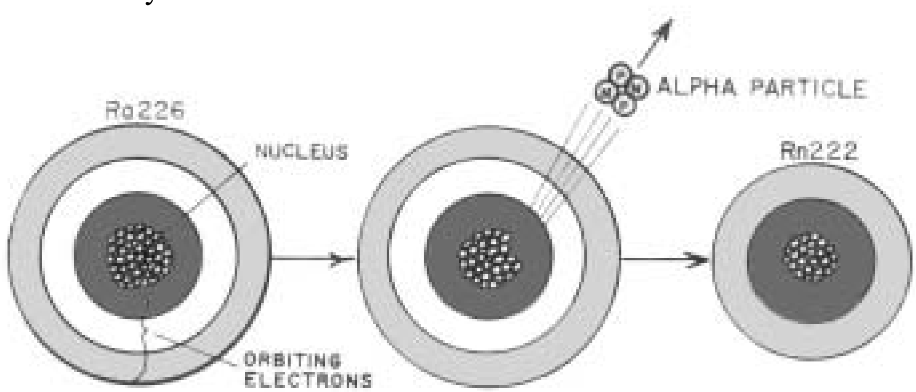

Figure 4. Conceptual Illustration - Alpha decay of Radium-226 to Radon-222

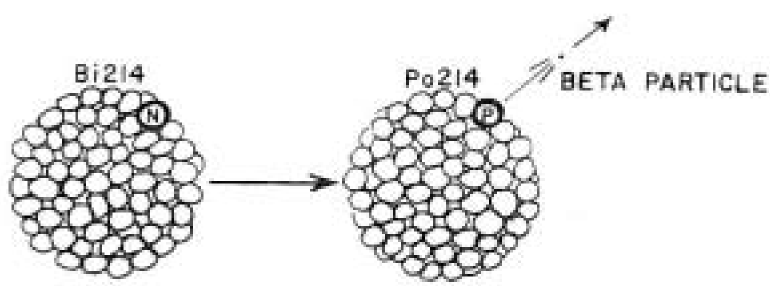

Figure 5. Conceptual Illustration - Beta decay of Bismuth-214 nucleus to Polonium-214 nucleus

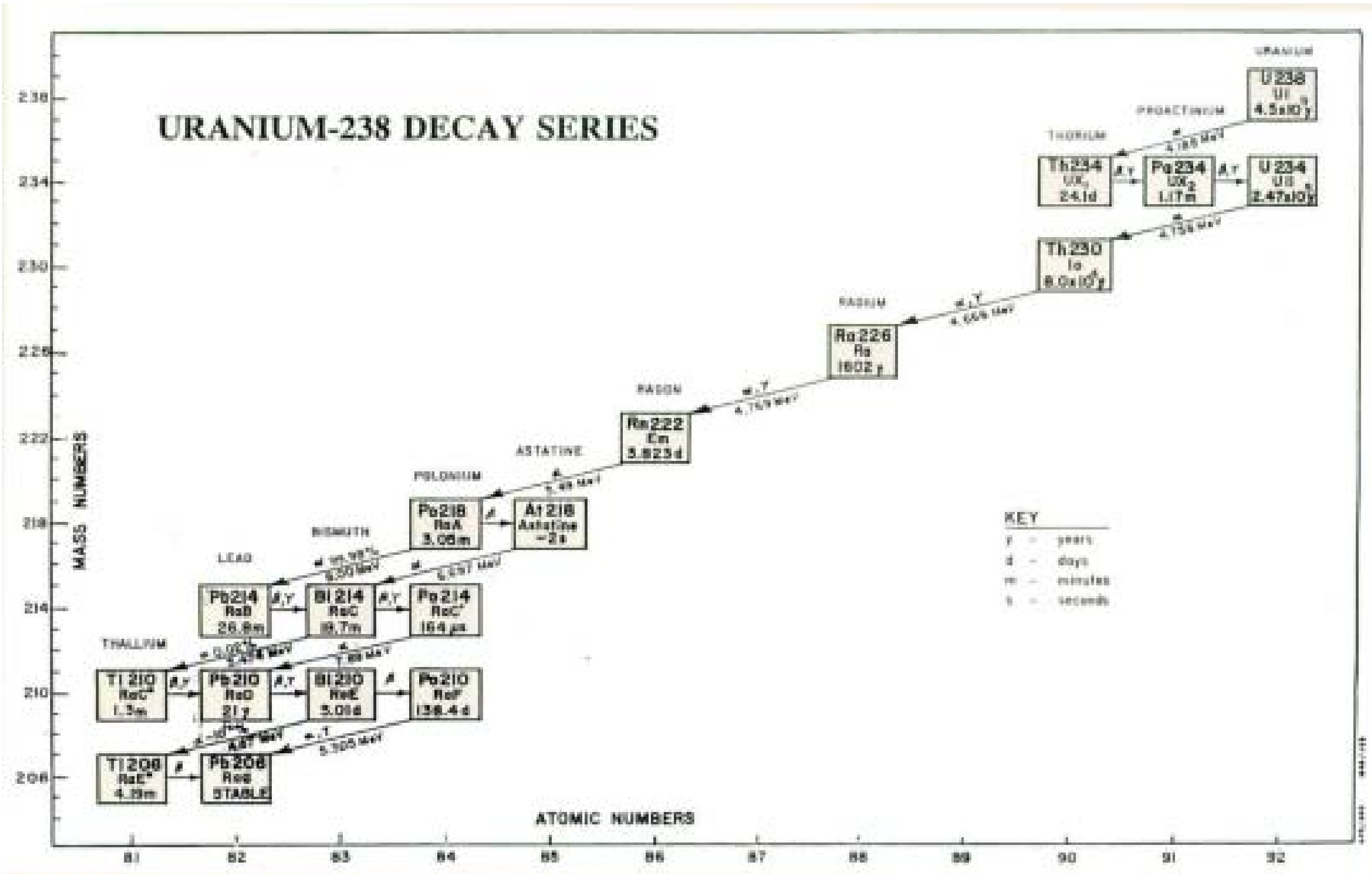

Figure 6. Uranium-238 Decay Series

The harmful effects of alpha, beta, and gamma radiation are primarily related to their ability to penetrate and alter living tissue. At a typical AML site, alpha and gamma radiation are of primary concern, and beta radiation should not be a problem. Alpha particles are not highly penetrating, but because of their high mass and energy (on the atomic level), they can be highly damaging to tissue surfaces. Gamma radiation is less damaging at the surface, but is highly penetrating and more apt to alter deeper tissues and vital organs.

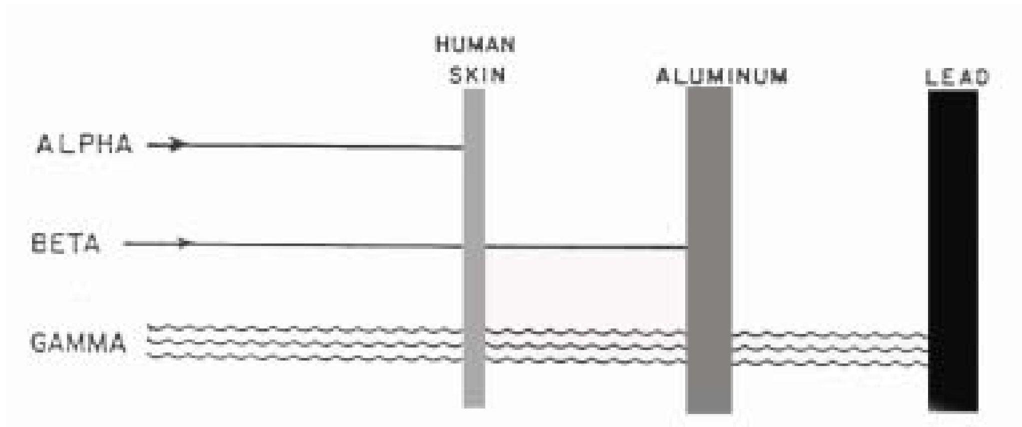

Figure 7. Conceptual Illustration - Penetrating powers of alpha, beta, and gamma radiation

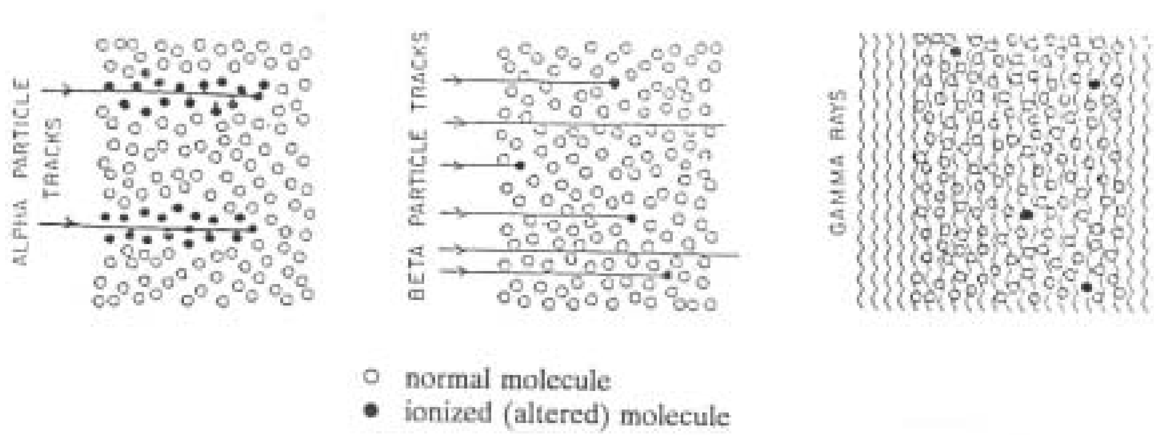

Figure 8. Conceptual Illustration - Ionization potentials for alpha, beta, and gamma radiation

The most dangerous alpha emitters in nature are the radon daughters, Polonium-218 [also called Radium A (RaA)] and Polonium-214 [Radium C′ (RaC′)]. There are two reasons for this: 1) RaA and RaC′ have relatively short half lives, which means that they are quite active, and 2) Radon daughters tend to get trapped in the delicate tissues of the lungs. The "trapping mechanism" is briefly described as follows: Radon is the only gas to occur in the U238 decay series at standard temperature and pressure, so at this point in the series, the source of radiation becomes airborne. Radon daughters, because they are solids at standard temperature and pressure, have a high tendency for attaching to or "plating out" on dust particles and mist droplets in the air when they are formed. Dust and mist can get trapped in the lungs when inhaled, thereby trapping attached radionuclides. These radionuclides then continue to decompose inside the lungs, damaging cells of the lung tissue.

With extreme or continued low-level exposure to radon progeny, lung tissue is scarred in such a manner that it cannot take oxygen into the bloodstream, thereby reducing breathing efficiency. Damage from this process is generally believed to be irreversible and cumulative through one's lifetime, and may lead to cancer. Radon gas is not typically as harmful as radon daughters because it has no trapping mechanism, i.e., since radon is a gas, it does not have an affinity for dust and mist, and since it's half life is 3.8 days, it is usually exhaled before decaying in the lungs.

While radon progeny are certain to be present to some degree in abandoned uranium mines, they are not limited to this occurrence. Radioactive elements may be associated with other mineralization episodes, and occur in varying proportions throughout nature. Any confined airspace may host radiological activity.

Since radon progeny are airborne, they are controlled by dust suppression and dilution through increased ventilation. Personal protection is achieved through use of breathing apparatus. In AML situations, the primary radiological concern is damage to lung tissue. Human skin effectively stops alpha radiation. While skin cells may get damaged from alpha exposure, the effect is much less hazardous than typical sunburn damage and the damaged cells are replaced with new, healthy cells.

For occupational safety and health (the mining industry, predominantly), radon daughter concentrations are usually measured in **working levels (WL)** α. **Picocuries per liter (pCi/l)** is also a common unit of measure, where 1 WL ≈ 200 pCi/l in air. Occupational standards require that respirators be worn in radon daughter concentrations in excess of 1 WL. Concentrations in excess of 10 WL, where radon gas concentrations become more significant, require a supplied-air breathing apparatus. Miners, furthermore, are only allowed a cumulative exposure of 692 **working level hours** per year. (1 **WLH** is the equivalent of 1 WL exposure for 1 hour, 2 WL for 1/2 hour, etc.) In the absence of specific regulations for the general public, the USEPA typically recommends general public limits at 10% of occupational standards. By this line of reasoning individuals in the general public should be allowed a maximum cumulative exposure of 69.2 WLH per year. **Because of the compounding effects of smoking and radon daughter exposure on the risk of cancer, smoking is not permitted in mine workings exceeding 0.3 WL.**

Gamma radiation, as stated above, is unlike alpha radiation in that it is highly penetrating. Gamma radiation is essentially independent of air circulation. The major gamma emitters in nature are Radium-226, Lead-214 [also called Radium B (RaB)], and Bismuth-214 [Radium C (RaC)]. Gamma radiation intensity decreases with distance from the gamma-emitting source. Because of its high penetration power, personal protection from gamma radiation is virtually impossible except through complete avoidance. Workers who come into frequent contact with gamma radiation should wear "dosimeters," often referred as "radiation badges" or "TLDs" (thermoluminescent dosimeters, a type of dosimeter commonly used). These sensors record cumulative gamma activity through time and are periodically read and discarded or turned in to a laboratory for analysis. When cumulative exposure for a worker approaches a regulated limit, that individual must be re-assigned to other duties away from sources of exposure.

A standard unit of measure for gamma radiation exposure has been the **roentgen equivalent man (rem)**. Gamma exposures are typically given in **millirems (mrem** or **mR**, where 1 mrem = 1 x 10^{-3} rem) per hour, or **microrems (µrem** or **µR**, where 1 µrem = 1 x 10^{-3} mrem = 1 x 10^{-6} rem**)** per hour. More recently, the **sievert (Sv), millisievert** (**mSv**), **and microsievert** (**µSv**) are being used to express gamma radiation values, where 1 Sv = 100 rem.

There are no acute gamma exposure limitations specified for mines. This is because typical gamma exposures at a mine (or, for that matter, a mill tailings impoundment) rarely approach levels where acute exposure is imminently hazardous. Background radiation values in the southwest, with a few noteworthy exceptions, are typically about 20 µR/hr. Many radiological AML sites have gamma emissions falling in the range from 100 to 300 µR/hr. Gamma radiation in these ranges is not considered to be excessively high for short-term exposures. Values above this may be encountered at particularly "hot" sites, however, and are particularly characteristic of sites where natural material has been concentrated by some technological means. For instance, sites operating under a license from the Nuclear Regulatory Commission (such as a nuclear power plant) require evacuation at 2 mR/hr.

It is important to note that the **regulations typically limit minors and pregnant women to 10% of the normal adult worker exposures**, since gamma exposures can be particularly damaging to developing organs and tissues of the fetus and children. For this reason, work around radioactive AML sites for minors and pregnant employees is discouraged.

The current USEPA Radiation Protection Guidance (RPG) for Exposure of the General Public states that there should be no exposure of the general public to ionizing radiation unless it is justified by the expectation of a net societal benefit from the activity causing the exposure. The RPG goes on to state that a sustained effort should be made to ensure that doses to individuals and to populations are maintained as low as reasonably achievable. ("**ALARA**" is a common term in industrial hygiene to emphasize this rule.) The combined radiation doses incurred in any single year from all sources of exposure covered under the RPG should not normally exceed an effective dose equivalent of 100 mrem for any individual. A source-specific limit of 10 mrem is recommended for individual sites.

There are three very basic principles for limiting exposure to ionizing radiation, thereby minimizing its effects:

TIME
DISTANCE
SHIELDING

Exposures are limited by minimizing the **time** of exposure, maximizing the **distance** between the receptor and the radiation source, and by **shielding** the receptor when exposure is unavoidable. As an additional precaution to minimize potential intake of radionuclides, **workers should not eat or smoke while at radioactive sites. Once off-site, it is important to wash off all dirt and dust and change out of dusty clothes before eating.**

The NPS Geologic Resources Division has instrumentation and expertise to monitor alpha and gamma emissions. Additionally, samples can be taken of soil and water around mines to check for **radium-226** (**Ra226**) levels. (Ra226, a solid, is the direct "parent" of Ra222, and is therefore the best parameter on which to test soil and water contamination. Soil and water radiological pollution standards for mines and mills are therefore often based upon Ra226 concentration.) GRD has been able to arrange for limited sample analysis through an informal agreement with the USEPA. These services are also available commercially but can be rather expensive.

For those interested, a detailed paper entitled Effective Management of Radiological Hazards at Abandoned Radioactive Mine and Mill Sites, is available by writing to National Park Service / GRD, Attn: John Burghardt, P.O. Box 25287, Denver, CO 80225-0287, or online at http://www2.nature.nps.gov/grd/distland/amlindex.htm#technicalreports.

Respirators should be worn in radon daughter concentrations in excess of 1 WL α.

The area should be evacuated at levels in excess of 10 WL α or 2 mR/hour γ.

Individual cumulative exposures should be limited to 69.2 WLH/year α and 100 mrem/year γ, and no more than 10 mrem/year γ from a particular site.

GAS	SYMBOL	SPECIFIC GRAVITY	EXPLOSIVE RANGE	HEALTH HAZARDS	SOLUBLE	COLOR	ODOR	TASTE	TLV*
AIR	**-**	1.000	-	-	-	-	-	-	-
OXYGEN	**O_2**	1.1054	highly combustible, but not explosive	21% - normal 17 % - panting 15% - dizziness 9% - coma 6% - death	-	-	-	-	lower: 19.5% upper: 23%
CARBON MONOXIDE	**CO**	0.9672	flammable @ 12.5 – 74.2%	highly toxic	slight	-	-	-	50 ppm
METHANE	**CH_4**	0.5545	5 – 15%	asphyxiant	slight	-	“gassy”	-	20% LEL (=1% by volume)
CARBON DIOXIDE	**CO_2**	1.5291	-	increases breathing	soluble	-	-	acidic	5,000 ppm (= 0.5%)
HYDROGEN SULPHIDE	**H_2S**	1.1906	4.3 – 45.5%	highly toxic	soluble	-	rotten eggs	sweet	10 ppm
RADON	**Rn**	7.5260	-	radiation	high	-	-	-	1 WL – respirator 10 WL – supplied air
SULFUR DIOXIDE	**SO_2**	2.2638	-	highly toxic	high	-	sulfur	acidic, bitter	5 ppm
NITROGEN	**N_2**	0.9674	-	asphyxiant	slight	-	-	-	-
NITROGEN DIOXIDE	**NO_2**	1.5894	-	highly toxic	slight	reddish-brown ➚	blasting smoke	blasting smoke	5 ppm
HYDROGEN	**H_2**	0.0695	4.0 – 74.2%	asphyxiant	-	-	-	-	-

* Threshold Limit Value – Standard alarm level on gas monitoring equipment.
➚ Noticeable only at high concentrations. Essentially colorless in concentrations likely to be encountered.

Figure 9. **MINE GAS SUMMARY**

G. **CHANGE: A Major Reason for Caution -** Abandoned mine sites are dynamic. Rock stability will deteriorate with time, so a portal or drift that may have been stable previously may now be a death trap. Heavy snow pack or a torrential spring storm may cause subsidence of a shallow mine feature, leaving a treacherous opening which may not have existed the last time a site was visited. Erosion may uncover new hazards such as abandoned explosives or openings that were not properly closed in the past. Perhaps the most dynamic aspect of change at AML sites is **airflow**, which is influenced by a mine's internal configuration, fluctuations in temperature, and changes in atmospheric pressure. Mines are said to "breathe," in that airflow at a given opening may be **static**, **incast**, or **outcast** under different atmospheric conditions. Because of these movements, a particular area may have good air on one site visit and bad air on the next visit. Air quality may even change in the course of an extended site visit. When conducting underground inspections, note the direction of airflow, especially at intersections where air from a different source may be encountered. Keep in mind that temperature and pressure changes may reverse airflow, bringing contaminated or oxygen-deficient air from different parts of a mine into an area that previously had good air. When conducting external surveys, avoid standing in air that is outcasting, or "exhaling" from an opening.

H. **RESCUE SITUATIONS -** Many people have lost their lives in attempting to rescue someone else. If an accident occurs while conducting an underground survey, the survey team should carefully evaluate the area before attempting to help. If the victim cannot be safely rescued, the appropriate local authority should be contacted. Sheriff's departments may have rescue personnel, or they may be linked to the state mine inspector's office and local active mines that have certified mine rescue teams. A **Job Hazard Analysis** (**JHA**) should include making prior contact with such groups and filing a survey plan with them, inclusive of scheduled check-in and check-out times from underground.

GUIDELINES FOR ABANDONED UNDERGROUND MINE RECONNAISSANCE

1. Underground exploration teams will realize that abandoned mines are unnatural, unstable, and temporary openings with a unique set of potential hazards. Caving experience is **no** substitute for underground mine experience.

2. Underground teams will be comprised of at least two people. If three or more people are present, one person will remain at the mine entrance. The exploration crew will check in with this person at predetermined time intervals.

3. At least one person on the team will be trained and experienced in underground mine safety and hazard recognition. This individual will lead the underground team and instruct inexperienced team members on potential hazards, underground mine safety procedures, and the use of safety equipment.

4. Safety equipment for **each individual** will include, but not be limited to:
   - **Hardhat**
   - **Steel-toed Footwear**
   - **Proper Lighting**, with at least one **backup lighting** source for **each person**.
   - **Eye Protection** - safety glasses are recommended; contact lenses are discouraged.
   - **Respirator**, which will be worn at all times in radon daughter concentrations in excess of 1 WL.

5. In addition to the above equipment, the **lead person** will be equipped with:
   - **Scaling Bar**
   - **Air Monitoring Equipment** (GRD uses a multi-gas detector which continuously monitors for oxygen, carbon monoxide, and explosive gasses. The meter has a visual display of gas concentrations, with warning lights and audible alarms that illuminate and sound when a threshold level of any of these gases is detected. GRD also uses monitoring equipment for alpha and gamma radiation.)

6. Inspectors must notify appropriate authorities before entering and upon leaving a mine. This can be done effectively by radio or cellular telephone.

7. Rock conditions will be checked with a scaling bar as the lead person enters the mine. Exploration will not continue if extensive barring down is required.

8. Underground teams will enter with the lead person in front and the rest of the survey crew following at a safe distance.

9. Underground teams will maintain voice contact with each other at all times.

10. If air detection equipment signals an alarm, or at the first sign of symptoms from bad air inhalation (i.e., headache, dizziness, slurred speech, nausea, etc.) in **any** team member, the symptoms will be mentioned verbally and the mine will be evacuated by **all** personnel **immediately**.

11. The survey crew will remain underground only long enough to complete the necessary work.

12. Unventilated shafts will not be entered.

13. Underground exploration will not proceed over caved areas.

14. Underground exploration teams will not proceed over rotten ladders or structures.

15. Standing pools of water on the floor will be probed for depth with a bar or pole before proceeding.

16. Suspected explosive or other hazardous materials will not be handled. Descriptive information will be recorded and the superintendent, chief safety officer, and regional blasting officer will be contacted to arrange for disposal.

QUIZ

For questions 1 & 2, prioritize from most to least often:

1. Accidents in active underground mines are caused by:

    a. explosives
    b. falling rock
    c. falling / tripping hazards
    d. contaminated or oxygen-deficient air
    e. heavy equipment

2. Accidents in abandoned underground mines are caused by:

    a. explosives
    b. falling rock
    c. falling / tripping hazards
    d. contaminated or oxygen-deficient air
    e. heavy equipment

Fill in the blank / multiple choice:

3. Looking in from outside, what is the first clue which indicates stability of rock in an underground mine?

    ____

4. Investigation inside abandoned mines by park staff for the purpose of conducting a hazard assessment is condoned by:

    a. the Mine Safety and Health Administration (MSHA).
    b. the Office of Surface Mining Reclamation and Enforcement (OSMRE).
    c. the Geologic Resources Division
    d. none of the above.

5. Oxygen-deficient air tends to:

    a. disseminate evenly throughout an enclosed area.
    b. stratify along the ceiling of an enclosed area.
    c. stratify along the floor of an enclosed area.
    d. any of the above, depending on the relative density of the gas replacing the air.

6. Unstable rock at an abandoned mine's portal (entrance) is often its most dangerous feature because:

   a. it is directly exposed to the forces of weathering.
   b. it is unsupported on the external surface.
   c. blasting into the hillside might have destabilized overlying strata far overhead.
   d. all of the above.

7. Ambient air contains ____ % oxygen (by volume). An area should be evacuated at concentrations less than ____ %.

True / False:

8. A "shaft" is defined as any mine opening, horizontal or vertical, leading from the surface to underground workings.

9. Barring any unnatural circumstances, if the air was suitable for breathing going into an abandoned mine, you should have no trouble breathing on the way out.

10. A person with extensive caving experience is qualified to investigate an abandoned mine.

11. If an abandoned mine is well timbered, it should be safe to enter.

12. Nearby operating mines may have certified mine rescue teams which could help in the event that someone needed to be rescued from an abandoned mine in your park.

13. GRD can make certain adits safe so that parks can leave them open to visitors as interpretive sites.

14. From a safety perspective, list ways in which active and abandoned mines may differ:

ACTIVE MINES	**ABANDONED MINES**
____________________	____________________
____________________	____________________
____________________	____________________
____________________	____________________
____________________	____________________
____________________	____________________
____________________	____________________

Abandoned and Inactive Mine Safety Training – Underground Mine Hazards
National Park Service Geologic Resources Division – August 2003

KEY:

1. b, e, c, d (underground fires), a
2. c, b, d, a, e (educated guess; no hard data available)
3. loose rock on floor
4. d
5. d
6. d
7. 20.95; 19.5
8. F
9. F
10. F
11. F
12. T
13. F
14.

ACTIVE MINES	ABANDONED MINES
positive (forced) ventilation system	natural airflow only (potential for bad air)
periodic maintenance, ground support	no maintenance, left to deteriorate, collapse, flood, etc.
periodic inspections (MSHA)	no inspections
operating equipment	inoperative equipment (less hazardous, usually)
stable explosives	unstable explosives
experienced, equipped personnel	untrained, unequipped visitors
emergency medical facilities/staff on-site	no medical facilities/staff on-site
mine rescue team	no mine rescue team