DRAFT

ELEVATED CONCENTRATIONS OF CARBON DIOXIDE IN HOMES

When we think of air, we generally think about a single element – oxygen. But air is actually a mixture of numerous elements and chemical compounds, some of which occur naturally and others of which are man-made. One such compound that is both natural and man-made is the gas carbon dioxide, or CO_2.

CO_2 is essential to life on Earth. Too much CO_2 in the air we breathe can be suffocating; too much in the atmosphere can contribute towards the greenhouse effect.

CO_2 has recently been recognized as a potential problem in western Pennsylvania as some families are finding high levels of the gas in their homes. Elevated CO_2 in buildings is not a new problem, but it may be becoming more common because of increased development on reclaimed surface coal mines. Like radon, high CO_2 is only a problem if it is not identified and dealt with appropriately. Fortunately, as with radon, there is a fairly simple means of correcting the problem.

CARBON DIOXIDE FACTS

Carbon dioxide is a nonflammable, colorless, and odorless gas. Under the right conditions of temperature and pressure, it can occur as a liquid or a solid (dry ice). It is approximately 1½ times heavier than air. Air is a mixture of many gases, the principal ones being nitrogen (78.1%), oxygen (20.9%), argon (0.93%), carbon dioxide (0.035%), and water vapor (between 0 and 4% depending on humidity). Trace amounts of ammonia, carbon monoxide, helium, hydrogen, krypton, methane, neon, nitrous oxides, ozone, sulfur dioxide, and xenon also occur in our air. Although the air we inhale contains only 0.035% CO_2, the gas makes up about 3 to 4% of the air we exhale.

CO_2 occurs naturally in both the atmosphere and in the ground. It enters the atmosphere naturally through volcanic activity, forest fires, and plant and animal respiration. Various manufacturing processes and the burning of fossil fuels also contribute to atmospheric CO_2 as man-made sources. It occurs naturally in the ground, in shallow soils, as the result of respiration by plants and microbes. CO_2 is especially abundant in the earth's mantle, dwarfing the total CO_2 in the atmosphere. It is expelled from the mantle into the atmosphere in great quantities by volcanic activity and other geothermal events. CO_2 also occurs in landfills through decomposition of organic matter, in underground coal mines, and even in some oil and gas reservoirs.

CO_2 can be dangerous in concentrations higher than 0.035% (see below), but it is also essential for everyday life. Plants breathe in CO_2 during the day, converting the carbon to organic materials required for them to live, and exhaling oxygen that other living things need. CO_2 also controls all animal, including human, respiration. It has practical value for many day-to-day human applications, such as fire extinguishers, dry ice for refrigeration, for carbonation of beverages, as a propellant in place of the less desirable freon gas, and in the production of plastics, rubber, and electronic components.

SOME DANGERS

As stated above, CO_2 can be dangerous in concentrations greater than 0.035% of normal air. The American Conference of Governmental Industrial Hygenists (ACGIH) and the Occupational Safety and Health Administration (OSHA) developed concentration limits, called Threshold Limit Values (TLVs), for CO_2 in the industrial workplace. TLVs include: 1) a time-weighted average concentration for an 8-hour workday and a 40-hour workweek of 5,000 parts per million (ppm), which equals 0.5% CO_2; and 2) a short-term exposure limit of more than 15 minutes 1.5% CO_2. What this means is that nearly all workers may be exposed day after day for a normal 8-hour workweek to a concentration of 0.5% CO_2 without adverse effect.

Symptoms of CO_2 exposure are variable. Exposure to CO_2 concentrations in excess of 1.5% can produce hyperventilation and headache. Prolonged exposure to high concentrations can result in death from asphyxiation. Table 1 identifies the most common symptoms of CO_2 exposure at different concentrations.

Table 1. Common symptoms associated with exposure to various concentrations of CO_2.

CO_2 Concentration	Symptoms
2%	50% increase in breathing rate. Prolonged exposure can cause headaches.
3-6%	Headaches, shortness of breath
6-10%	Headaches, shortness of breath, tremors, visual impairment, unconsciousness
>10%	Unconsciousness (potentially without warning)

CO_2 AND COAL MINING

CO_2, methane, and other gases are integral parts of coal, adhering to the surface of the coal in microscopic pores and along fracture surfaces. Mining frees these gases from the coal where they can concentrate in dangerous proportions, particularly in underground mines. Miners call CO_2 "blackdamp" or "chokedamp" because of its suffocating effect in mines ("damp" is a mining term for a dangerous gas).

Elevated concentrations of CO_2 can occur in the spoil gas (air) of reclaimed surface coal mines. When coal surface mines are reclaimed, the mine operator fills in the mine pit, returns the landscape to its approximate original configuration and restores the topsoil and vegetation. In coal containing significant amounts of sulfur minerals such a pyrite, groundwater flowing through the coal typically reacts with the pyrite to form sulfuric acid and "yellowboy" (Equations 1 and 2), the iron-rich material that stains streams bright orange.

$4 FeS_2 + 15 O_2 + 14 H_2O \rightarrow 4 Fe(OH)_3 + 8 H_2SO_4$ Equation 1

(pyrite + oxygen + water → "yellowboy" + sulfuric acid)

$H_2SO_4 + CaCO_3 \rightarrow Ca^{2+} + SO_4 + H_2O + CO_2$ Equation 2

(sulfuric acid + calcite → calcium + sulfate + water + carbon dioxide")

Limestone and other rocks containing carbonate minerals such as calcite (calcium carbonate – $CaCO_3$) are the primary alkaline materials found on mine sites and therefore in mine spoil. CO_2 is one of the products that is produced when carbonate minerals react with the acid that is produced from pyritic rocks. CO_2 can also occur as a result of microbial respiration in the mine spoil.

Thus, CO_2 can enter soils and shallow rock formations where it can migrate from through rock fractures, permeable soil, or broken up rock (such as mine spoil or fill from road construction).

CO_2 PROBLEMS

CO_2 entering homes would be of little concern in western Pennsylvania except for development on areas that are surface mined for coal. Because of advances in mine reclamation surface mines are no longer a blight on the landscape, but are an attractive piece of real-estate. This includes reclaimed surface coal mines in which acid mine drainage is reacting with carbonate minerals to release CO_2. Surface coal mines are not the only situation in which acidic water comes in contact with carbonate minerals and makes CO_2, but it is one of the more prominent and predictable.

Changes in barometric pressure drive gases, such as air, from higher to lower pressure areas. A building constructed in coal mine spoil represents a low-pressure area. When barometric pressure falls, soil gases typically migrate outward from the ground into the atmosphere. It can also migrate into homes through cracks or gaps in floors and walls, construction joints, and gaps around water, gas, and sewer lines (Figure ___.) Movement and concentration of CO_2 in homes also fluctuates with changes in interior building pressure.

Because CO_2 is odorless and colorless, families living in homes affected by high concentrations typically aren't aware of the problem immediately. They often learn of the problem only as a result of physical ailments (e.g., labored breathing, headaches, exhaustion) and/or trouble starting or maintaining a flame (e.g., striking a match, lighting a candle, or keeping a pilot light burning). When anything like these symptoms occur, they should be taken seriously. But don't assume immediately that CO_2 is the culprit, because other gases can cause similar problems. The home needs to be sampled for indoor-air quality using portable meters properly calibrated and equipped with oxygen, carbon monoxide, and CO_2 sensors. The meter should be equipped with a flame ionization detector in case hydrocarbon gases such as methane are also suspected. Finally, sampling the air for laboratory analysis will precisely determine which compounds are present and in what concentrations.

WHAT CAN YOU DO?

The best short-term remedy for stopping CO_2 migration into homes is to fill floor cracks, construction joints, cracks in walls, gaps in suspended floors, and gaps around service lines with an impermeable seal such as radon-resistant caulk or hydraulic cement. These remedies will be effective in reducing and helping eliminate CO_2 migration into a home.

A reverse flow or positive pressure radon system is, at this time, the most effective long-term strategy for eliminating CO_2 problems. Standard radon systems, which draw air from under the basement slab and vent the gas to the outside, work well in reducing small (i.e., a few parts per million) concentrations. However, because these radon systems create low-pressure areas beneath basement floors, they tend to draw gases toward the home. Therefore, with higher concentrations of CO_2 they will be ineffective at best, or potentially contribute toward the problem. A reverse radon system takes outside fresh air and forces it under the basement slab. This increases the air pressure around a home foundation and drives the CO_2 away from the building (see Figure __).

As with a standard radon system, a reverse flow radon system should be designed and installed by a qualified professional. Firms installing radon mitigation systems must be certified by the Pennsylvania Department of Environmental Protection (DEP). Information on radon control systems and their construction requirements can be found in the International Building Code, Appendix F or EPA's Technical Guidance, "Radon Reduction Techniques for Detached Houses." These same requirements can be used to correct CO_2 problems in houses simply by reversing the ventilation process – forcing the air below the building instead of drawing air towards the building. In addition, wallmounted continuous CO_2 monitors should be installed, particularly in home basements, to check both CO_2 concentrations in the home and the long-term effectiveness of the ventilation system.

If you have a problem with CO_2, Pennsylvania scientists can assit in establishing the source of the CO_2 by doing analyses of the type of carbon atom. Two agencies are can assist with this, DEP's Environmental Cleanup Program (412-442-4000) and the Pennsylvania Geological Survey (412-442-4235). The DEP Bureau of Radiation Protection can contacted for assistance and for free literature on protecting houses from radon, for those homeowners interested in installing reverse radon systems. Call 412-442-4000 to request this assistance and literature. Homeowners wishing to determine if their property lies on a reclaimed strip mine, or above an active or abandoned underground coal mine, should call the nearest DEP District Mining Office.

FIGURES

Figure ___.

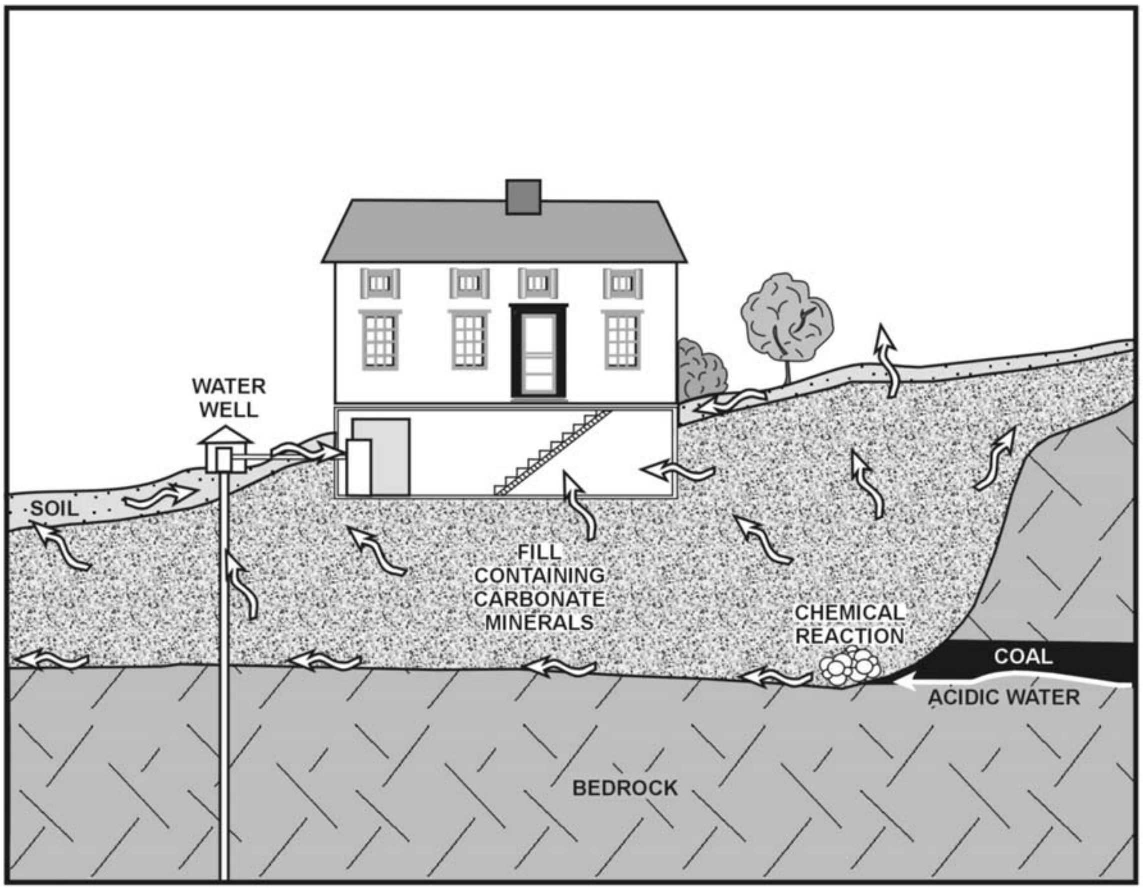

Figure ___.