NIOSH HEALTH HAZARD EVALUATION REPORT

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West Virginia Department of Environmental Protection
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PREFACE

The Respiratory Disease Hazard Evaluations and Technical Assistance Program (RDHETAP) of the National Institute for Occupational Safety and Health (NIOSH) conducts field investigations of possible health hazards in the workplace. These investigations are conducted under the authority of Section 20(a)(6) of the Occupational Safety and Health (OSHA) Act of 1970, 29 U.S.C. 669(a)(6), or Section 501(a)(11) of the Federal Mine Safety and Health Act of 1977, 30 U.S.C. 951(a)(11), which authorize the Secretary of Health and Human Services, following a written request from any employers or authorized representative of employees, to determine whether any substance normally found in the place of employment has potentially toxic effects in such concentrations as used or found.

RDHETAP also provides, upon request, technical and consultative assistance to federal, state, and local agencies; labor; industry; and other groups or individuals to control occupational health hazards and to prevent related trauma and disease. Mention of company names or products does not constitute endorsement by NIOSH.

ACKNOWLEDGMENTS AND AVAILABILITY OF REPORT

This report was prepared by Jeana M. Harrison, MS; Carol Y. Rao, Sc.D.; and Lisa G. Benaise, MD, MPH of RDHETAP, Division of Respiratory Disease Studies (DRDS). Field assistance was provided by Thomas Jefferson. Desktop publishing was performed by Terry Rooney. Review and preparation for printing were performed by Penny Arthur.

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Highlights of the NIOSH Health Hazard Evaluation

Evaluation of Carbon Dioxide Infiltration into a Residence

NIOSH received a technical assistance request from the West Virginia Department of Environmental Protection to assist with the investigation of a residence with an oxygen-deficient environment. Investigators found elevated carbon dioxide concentrations above current workplace exposure standards due to infiltration from the ground into the home.

What NIOSH Did

- Provided sampling equipment
- Interviewed homeowners
- Conducted literature search
- Advised West Virginia Department of Environmental Protection on health and safety issues associated with working in a hazardous environment
- Advised remediation workers about safety for confined space entry

What WVDEP and NIOSH Found

- Elevated concentrations of carbon dioxide inside residence
- Homeowner, WVDEP investigator, and contractor symptoms consistent with exposures to elevated concentrations of carbon dioxide and low oxygen levels
- Carbon dioxide likely came from the remediated surface coal mine or the abandoned underground coal mine, both of which are located beneath the home.

What State and Local Agencies Can Do

- Alert clinicians, especially those in emergency departments, to the symptoms associated with high carbon dioxide exposures
- Alert residents living above underground and reclaimed surface mines to the potential hazards of mine gas infiltration into their homes
- Alert utility workers and first responders to potentially hazardous air environments (e.g., oxygen deficient, elevated carbon dioxide) in enclosed spaces
- Consider instituting a program to assist residents in assessing risks and hazards of mine gas infiltration into their homes

What Homeowners Can Do

- Determine if surface or underground coal mines exist beneath their properties and then determine whether there could be potential carbon dioxide gas infiltration by using carbon dioxide meters.
- Implement mitigation if gases are infiltrating into the home
- Continue to monitor symptoms and take action if they return
- Consider installation of carbon dioxide monitors in the affected spaces

What To Do For More Information:
We encourage you to read the full report. If you would like a copy, either ask your health and safety representative to make you a copy or call 1-513-841-4252 and ask for HETA Report #2004-0075-2944

Health Hazard Evaluation Report 2004-0075-2944
West Virginia Department of Environmental Protection
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SUMMARY

In June 2001, a middle-aged couple with a history of smoking moved into a newly built, two-story, wood-framed home with a finished basement and adjacent crawlspace on land that was formerly mined. Shortly after occupancy, the 42-year old woman noted new-onset shortness of breath, lightheadedness, dizziness, and fatigue while in the basement. Within a few months, the previously healthy 42-year old man reported new-onset mild confusion, poor concentration, headache, and blurry vision while fabricating fishing poles in his basement workshop. These symptoms are consistent with exposure to elevated carbon dioxide and low oxygen concentrations. Their symptoms always resolved within minutes after leaving the basement.

NIOSH received a technical assistance request in December 2003, from the West Virginia Department of Environmental Protection (WVDEP) to assist with the investigation of a residence where they found an oxygen-deficient environment in the basement and crawlspace areas. Carbon monoxide, methane, and 33 other gases were not detected (using an AIM Model 3250, IST-AIM, Horseheads, NY, USA), which led investigators to suspect that carbon dioxide could be displacing oxygen in the basement and crawlspace.

NIOSH provided sampling equipment and safety and health information to WVDEP. WVDEP investigators found elevated carbon dioxide concentrations in the home. In addition, NIOSH conducted medical interviews with the homeowners and advised remediation workers about hazards and requirements for confined space entry. NIOSH informed the local and state health departments about the elevated carbon dioxide concentrations at this residence.

A modified direct-reading carbon dioxide monitor (detection range up to 50% carbon dioxide) was used for short-term sampling from December 2003 until February 2004. Concentrations of carbon dioxide in the crawlspace were as high as 9.5% in the crawlspace, 11% in the crawlspace gravel, and 12% in the floor drain (outside air has a carbon dioxide concentration of 0.035%). Carbon dioxide levels on the upper floors exceeded the upper limit of detection (1%) of the standard carbon dioxide monitor. Oxygen concentration in the basement was intermittently deficient during the evaluation, with levels measuring as low as 14% in the crawlspace. In addition, WVDEP investigators took a soil gas sample and an air sample from a mine drainage pipe for carbon isotopic composition analysis, which led to the determination that the source of the carbon dioxide was likely from a carbonate source. Limestone, a carbonate, is the most likely source on this land since it is generally used during the remediation of surface mines.

NIOSH recommendations to homeowners with symptoms consistent with carbon dioxide exposure or low oxygen concentrations include:

- Determine whether the home is located above an underground coal mine or a reclaimed surface coal mine and then determine whether there could be potential carbon dioxide gas infiltration by using carbon dioxide meters.
- Implement mitigation techniques to reduce infiltration, if found,
- Monitor symptoms and take action, and
- Consider installation of carbon dioxide monitors in the affected spaces.

NIOSH recommendations to state and local agencies include:

- Alert clinicians, especially those in emergency departments, to the symptoms associated with elevated carbon dioxide exposure,
- Alert residents living on underground and/or reclaimed surface mines to the potential hazards of mine gas infiltration into their homes,
- Alert utility workers and first responders to the existence of potentially hazardous air environments (e.g., oxygen deficiency, elevated carbon dioxide) in enclosed spaces, and
- Consider instituting a program to assist residents in assessing risks and hazards of mine gas infiltration into their homes and providing information on the mitigation of these gases.

The couple had symptoms consistent with exposures to elevated carbon dioxide levels. Their chronic exposures to carbon dioxide were likely greater than the NIOSH 8-hour Recommended Exposure Limit of 5000 ppm (0.5%) carbon dioxide and the 15-minute short-term exposure limit of 30,000 ppm (3%) while in the basement. The dramatically elevated carbon dioxide levels in this home are ground-related, as shown by the high levels in the crawlspace gravel, basement floor drain, and in soil samples surrounding the home. Sources of carbon dioxide from abandoned mines include decaying timber in mine spoil, acid mine drainage reactions with limestone, and emissions from the coal itself. CO_2 concentrations in excess of 25% and oxygen concentrations as low as 10% have been recorded in homes above coal mines in Pennsylvania and in Great Britain. Preventive construction for mining-related indoor air quality problems includes sealing cracks, maintaining positive pressure in relation to the ground, and ventilating subsurface areas in a manner similar to that used for radon mitigation. Gas companies, first responders, and health providers should be aware of the possibility of oxygen deficiency and carbon dioxide toxicity when occupants of buildings in areas with reclaimed or abandoned coal mines complain of shortness of breath, palpitations, dizziness, confusion. Another sign of oxygen deficiency or elevated carbon dioxide concentrations is the difficulty maintaining a pilot light on a gas appliance such as a water heater. In affected homes, homeowners, indoor workers, public utility workers, emergency response workers, and remediation workers may be at risk from dangers associated with confined space entry. This dictates increased public awareness and special training for workers, careful measurement of the environment to assess potential risks, precautions to avoid incapacitation, and preparation for rescue should a worker encounter immediately dangerous conditions.

Keywords: carbon dioxide, indoor air quality, IAQ, house, coal mine, oxygen deficiency, panic attacks, shortness of breath, throat irritation, neurological symptoms, carbonic acid, mine gas infiltration

Table of Contents

INTRODUCTION

On December 3, 2003, the National Institute for Occupational Safety and Health (NIOSH) received a telephone call from the West Virginia Department of Environmental Protection (WVDEP) regarding possible high concentrations of carbon dioxide in a single-family home in Morgantown, West Virginia. WVDEP found an oxygen-deficient atmosphere in the basement and crawlspace areas. Carbon monoxide, methane, and 33 other gases were below the limits of detection, which led investigators to suspect that carbon dioxide could be displacing oxygen in the air. On December 4, 2003, NIOSH received a technical assistance request from WVDEP, to assist them with measuring carbon dioxide concentrations because they did not have the needed monitoring equipment.

A NIOSH industrial hygiene technician went to the site on December 3 and December 9, 2003, to deliver real-time carbon dioxide and oxygen meters. On December 11, 2003, WVDEP requested assistance with confined space safety in the crawlspace of the home. At that time, two NIOSH industrial hygienists went to the site to explain the Occupational Safety and Health Administration standard for confined spaces (29 CFR 1910.146).[1] A NIOSH physician interviewed the male homeowner on December 19, 2003. A West Virginia state epidemiologist assisted with homeowner interviews on January 5, 2004. NIOSH provided information and air sampling equipment to WVDEP through March 22, 2004.

BACKGROUND

Construction of the two-story house, on a 10-acre lot, was completed in June 2001. Approximately three-quarters of the house sits over a full finished basement that has a concrete slab floor. The remainder of the house sits above a three-foot high, unfinished crawlspace that has a gravel floor. The crawlspace is adjacent to the finished basement (Figure 1). The exterior walls of the basement and crawlspace are constructed with concrete block, including the interior dividing wall between the basement and the crawlspace. The living areas of the home were constructed using standard wood framing. The homeowners previously lived in a mobile home on the lot for two years with no health complaints. Using mine maps, WVDEP determined that the property is situated on a surface mine that was reclaimed in 1987 and above an underground coal mine that was abandoned in 1966. The reclaimed surface-mined land had been approved for public use by WVDEP.

The homeowners reported a series of incidents dating back to the time they first occupied the home in 2001. The pilot light on the water heater in the basement recurrently went out, and the couple's calls to the gas company resulted in inspections of the gas meter. In June 2002, the couple called the local fire department because they were concerned that a gas leak could have extinguished the pilot light. Short-term monitoring by the fire department for carbon monoxide and methane gas was negative. In addition, a home carbon monoxide monitor in the basement never signaled.

Shortly after occupancy, the 42-year old female, who had a history of smoking, noticed new-onset shortness of breath, dizziness, and fatigue while in the basement. Her symptoms progressively increased until she could not tolerate extended periods in the basement due to shortness of breath, racing heartbeat, and panic. She noted similar symptoms upon awakening in her first-floor bedroom on July 8 and 9, 2003, which prompted visits to the local emergency department on both days. She was diagnosed with new-onset asthma and a cardiomyopathy attributed to a 1997 viral (varicella) infection. Despite the use of cardiac and respiratory medications, including the use of a short-term inhaled bronchodilator, the woman continued to experience problems when in the basement.

A few months after the woman developed symptoms, the 42-year old male, with a history of smoking, reported new-onset mild confusion, poor concentration, headache, and blurry vision while working in his basement workshop. In

October 2003, the man noted rapid respiration and eye burning while in the crawlspace for a three-hour period to investigate potential gas leaks. He later noticed hoarseness. In November 2003, the man reported that a contractor became breathless inside the crawlspace. That day, a fire department visit again showed negative readings for carbon monoxide and methane. Four hours later, after spending 20 minutes in the crawlspace with the contractor, the man noticed shortness of breath and went to a hospital emergency department where he was diagnosed with acute carbon monoxide exposure on the basis of a mildly elevated carboxyhemoglobin level of 6 percent and labored breathing. He was treated with oxygen and discharged from the hospital. Due to poor concentration and fatigue, the man missed five days of work, remaining at home during that time.

On December 2, 2003, two contractors noted onset of hoarseness and a rapid heart rate while at the entrance to the basement crawlspace. The fire department responded again, and the first firefighter at the scene felt a strong draft at the entrance to the crawlspace that "took his breath away." None of the firefighters detected abnormal odors or tastes; they tested for, but did not detect, carbon monoxide, or methane. The firefighters then called the Monongalia County Hazardous Incident Response Team (HIRT), who found an oxygen-deficient atmosphere in the basement and crawlspace areas of the home, although they also found no detectable levels of carbon monoxide, methane, or the 33 gases screened by HIRT's gas monitoring instrument. HIRT called WVDEP to conduct further investigation, according to emergency response protocol. The WVDEP investigator experienced an increased heart rate while in the basement and found oxygen concentrations as low as 14 percent by volume in the crawlspace (normal concentration is 20.9% by volume). Complete combustion furnaces emit carbon dioxide, as opposed to carbon monoxide, which lead WVDEP to hypothesize that carbon dioxide gas could be displacing the oxygen in the residence. WVDEP did not have carbon dioxide monitors, so they submitted a technical assistance request to NIOSH for monitoring equipment and technical guidance.

METHODS

NIOSH provided four direct-reading carbon dioxide monitors to the WVDEP: two Q-TRAK™ monitors (TSI Inc., St. Paul, MN, USA) with a range from 0 to 5,000 parts per million (ppm), one standard Eagle™ (RKI Instruments, Inc., Hayward, CA, USA) with a range from 0 to 10,000 ppm, and an additional modified Eagle™ that measures up to 500,000 ppm (50 percent carbon dioxide). NIOSH also provided one T82 single gas oxygen meter (Industrial Scientific Corporation, Oakdale, PA, USA.) WVDEP used the direct-reading monitors to instantaneously determine carbon dioxide and oxygen levels in the basement, crawlspace, and living areas of the home. Investigators used monitors to find the source of the carbon dioxide by holding them close to potential sources such as the furnace, cracks in the basement's concrete floor, in floor drains that tie into the home's French drain system, hairline cracks in the foundation, the abutment of the drywall and foundation, and in the crawlspace ambient air. In addition, WVDEP used the Eagle™ monitors in conjunction with a three-foot metal probe with holes in the bottom that was inserted into the ground to obtain an estimate of carbon dioxide gas present in the soil in the crawlspace and on the property.

Once the possible sources of carbon dioxide were identified, WVDEP collected "soil gas" samples on December 19 and December 23, 2003 that they sent to Isotech Laboratories, Incorporated (Champaign, IL, USA) for carbon isotopic composition and general chemical composition analysis. NIOSH provided a Gilian® air sampling pump (Sensidyne, Inc., Clearwater, FL, USA) and several Tedlar® bags with a single stainless steel hose/valve and septum fitting (SKC, Inc., Eighty-four, PA, USA) for use with WVDEP's metal probe to take a soil gas sample in the crawlspace of the home. Similarly, an air sample was taken at a drainage pipe located nearby, but not on this property, that usually drains water from the underground mine. When water flow from the drainage pipe is low, air is released as well.

The NIOSH physician and state-based epidemiologist interviewed the homeowners on December 19, 2003, and January 5, 2004. The homeowners gave a detailed timeline of events leading up to WVDEP's involvement on December 3, 2003. The homeowners provided medical records for recent emergency room and physician visits in relation to symptoms they associated with the home.

RESULTS

Elevated carbon dioxide concentrations were measured inside the home. WVDEP found a carbon dioxide concentration gradient with highest levels in the basement floor drain (which may have been improperly connected to the French drain allowing gas to enter the home) and in the crawlspace; to the lowest concentrations found on the upper floors of the home (Table 1). On December 3, 2003, carbon dioxide concentrations on the first floor exceeded the upper limit of detection (1 percent) for the standard carbon dioxide monitor. Basement carbon dioxide concentrations remained elevated, whether or not the furnace was operating. Basement oxygen concentration measurements were intermittently deficient, as shown in the table. WVDEP noted sudden increases in carbon dioxide and decreases in oxygen readings based on the weather, specifically when low pressure systems moved through the area.

The soil gas sample taken in the crawlspace on December 19 showed a high concentration of carbon dioxide, up to 8.7% (Table 2). The mine drainage pipe sample contained less than one percent CO_2 and was somewhat isotopically different than the crawlspace sample. The stable isotopic composition of carbon, expressed in the delta notation, was -8.70 per mil in the crawlspace ground gas sample and -6.50 per mil for the mine drainage pipe air sample. The mine drainage pipe air sample may have been diluted with ambient outdoor air or these two samples could represent different gases or sources. The carbon isotopic analysis of the crawlspace sample indicates a carbonate source, with limestone being the most likely source, according to the laboratory.[2]

DISCUSSION AND CONCLUSIONS

WVDEP determined the source of the carbon dioxide to be geologic, and was most likely the result of a chemical reaction of acid mine drainage with limestone from the surface mine spoil or from material used as fill around the perimeter of the house.[3] The Pennsylvania Department of Environmental Protection has found similar situations in various homes in southwestern Pennsylvania.[4] Other states have reported similar cases in homes built on former landfill sites.[5] Great Britain and Russia have documented numerous cases of carbon dioxide infiltrating homes from underground mines.[6,7,8] Magma is another known geologic source of carbon dioxide in the ground, as was found in Lake Nyos in Cameroon and at Mammoth Mountain in California.[9,10] Magma and landfills were not considered as potential sources of carbon dioxide in this investigation.

The couple from this West Virginia home had symptoms consistent with exposures to elevated carbon dioxide concentrations and possible oxygen deprivation. The woman's incidental cardiomyopathy may have predisposed her to become symptomatic in this environment. Panic attacks have been associated with exposures to high carbon dioxide concentrations (13%).[11] The man and two contractors reported throat irritation. Acute exposures to very high concentrations of carbon dioxide (from 15 to 100%) have been used by researchers to induce mucosal irritation and evaluate pain thresholds.[12,13] Carbon dioxide forms carbonic acid, a weak dibasic acid, when dissolved in water (e.g., mucosal moisture). Mucosal irritation, burning, and an unpleasant taste have been reported in human studies of acute high carbon dioxide exposures (greater than 30%).[13,14]

The health effects of carbon dioxide levels between 2 percent to 10 percent (20,000 – 100,000 ppm) include recurrent headache, tachycardia, dizziness, fatigue, rapid breathing, and visual and hearing dysfunction. Exposure to higher (greater than 10%) carbon dioxide concentrations may lead to unconsciousness or death within minutes of exposure.[14,15] A measurement of 9.5 percent carbon dioxide in the crawlspace was more than twice the Immediately Dangerous to Life and Health (IDLH) value of 4 percent (40,000 ppm).[15] Health effects from carbon dioxide exposure are directly related to the severity and duration of exposure, as well as the activity level of the exposed individual.

The homeowners initiated remediation efforts based on recommendations from the Office of Surface Mining, U.S. Department of Interior. Remediation included installing a new egress point (door) and additional ventilation from the crawlspace, sealing all cracks in the foundation, and installing a reverse-flow ventilation system in the crawlspace. The crawlspace of the home was determined to be a confined space because of the oxygen-deficient atmosphere and potentially toxic concentrations of carbon dioxide. The construction workers hired to remediate the crawlspace were not trained on confined space entry. Remediation workers, utility workers, and emergency responders are at risk when working in confined or enclosed spaces of buildings with high carbon dioxide concentrations. Because carbon dioxide is heavier than air, it displaces oxygen in enclosed environments. During low-barometric atmospheric conditions, the carbon dioxide flux, the rate at which the carbon dioxide leaves the ground, increases significantly.[4,8] Anyone working in enclosed spaces under these conditions should be trained on confined space entry in accordance with proper procedures.[16]

Renovations to the crawlspace and basement are on-going to redirect ground gases and to limit infiltration indoors. Since remediations began, carbon dioxide concentrations have decreased (maximum of 0.23 percent, or 2,300 ppm, measured in the basement as reported by WVDEP) and oxygen concentrations have returned to normal. The couple's symptoms have resolved, though they report limiting their time in the basement and keeping upper floor windows open. The homeowners installed carbon dioxide alarms similar to those used in beverage carbonation facilities in the basement and kitchen. These alarms are not direct-reading and will not alert the homeowners to high concentrations until they reach a set point. The basement alarm is set at three percent (30,000 ppm), while the kitchen alarm is set at 0.5 percent (5,000 ppm). Remediation has significantly reduced the carbon dioxide concentration in the entire home, although the gas may find another migration path into the home. The homeowners are currently unable to monitor carbon dioxide concentrations because they do not own carbon dioxide detection equipment.

The dramatically elevated carbon dioxide concentrations in this home are ground-related, as shown by the higher levels in the crawlspace gravel and basement floor drain, and the high levels found in soil samples surrounding the home. Sources of carbon dioxide from abandoned mines include decaying timber in mine spoil, acid mine drainage reactions with limestone, and emissions from the coal itself. During periods of low barometric pressure, mine gases are more likely to surface. The virtually unknown problem of carbon dioxide infiltration from the ground may affect many homeowners in mining states. The homeowners in this case repeatedly called their local fire department for assistance, but they were unable to determine a cause for their symptoms. In West Virginia, there is no single agency for homeowners to call if they experience such problems in their homes. In southwestern Pennsylvania, carbon dioxide concentrations in excess of 25% and oxygen concentrations as low as 10% have been recorded in homes above mines.[4] Some states, including Pennsylvania and Ohio, have programs in place to assist homeowners in remediating their homes.[17,18] Preventive construction for mining-related indoor air quality problems includes sealing cracks, maintaining positive pressure, and using subsurface ventilation techniques similar to those used for radon mitigation techniques.[4]

The public health implications of this report pertain to the indoor environments of both homes and workplaces. Gas companies, first responders, and health providers should be aware of the possibility of oxygen deficiency and carbon dioxide toxicity when occupants of buildings located on reclaimed or abandoned coal mines complain of shortness of breath, or palpitations. An environmental sign of an oxygen-deficient atmosphere is a difficulty maintaining pilot lights. In addition, homeowners, indoor workers, public utility workers, emergency response workers, and remediation workers may be at risk from dangers similar to those recognized in confined space entry.[16] This requires special training for these workers, carefully measuring the environment to assess potential risks, taking precautions to avoid incapacitation, and making preparations for rescue should the worker encounter unfavorable conditions.[1] In locations where similar problems are recognized, building codes for new construction may be an appropriate aid to prevention.

RECOMMENDATIONS

- The homeowners in this case should continue to monitor their symptoms and contact their local health department and family physician if their symptoms return.
- In general, homeowners should realize that they may not be able to reduce their indoor carbon dioxide concentrations to the ambient outdoor air concentration of 350 ppm. Studies have shown that healthy people exposed to approximately 2000 ppm do not notice health effects or symptoms.[14]
- If it has been determined that the source of the airborne contaminants is from soil gas, homeowners should follow the Office of Surface Mining's recommendations for reduction of ground gas infiltration, such as implementing radon-resistant construction with a reverse-flow ventilation system that creates a positive pressure at the point of entry.[4]
- Homeowners with known carbon dioxide problems should consider the installation of carbon dioxide alarms.
- Remediation workers should be trained on confined space entry before working in a confined space with limited egress. Management should test the atmosphere for safe entry (training required), and establish rescue procedures before entry. Management should also evaluate the space for lockout/tagout procedures, adequate ventilation, proper work procedures, required personal protective equipment, and necessary communication systems. If personal protective equipment is required, workers should have appropriate training before entry into the space.
- State and local agencies in states with past or current mining activities should consider publicizing the problem of carbon dioxide infiltration into homes and buildings. For example, local clinicians, especially those in emergency departments, should be familiar with the symptoms associated with high carbon dioxide exposures, which are similar to many other health problems that they may consider first, like someone with heart problems. In addition, utility workers and first responders should be aware of potential confined space issues and the possibility of oxygen deficiency and carbon dioxide toxicity in buildings located on reclaimed or abandoned coal mines. This serious and potentially fatal public health and environmental issue may require collaboration among state and local agencies.

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EVALUATION CRITERIA

As a guide to the evaluation of the hazards posed by workplace exposures, NIOSH field staff employ environmental evaluation criteria for the assessment of a number of chemical and physical agents. These criteria are intended to suggest levels of exposure to which most workers may be exposed up to 10 hours per day, 40 hours per week for a working lifetime without experiencing adverse health effects. It is important to note that not all workers will be protected from adverse health effects even though their exposures are maintained below these levels. A small percentage may experience adverse health effects because of individual susceptibility, a pre-existing medical condition, and/or hypersensitivity (allergy). In addition, some hazardous substances may act in combination with other workplace exposures, the general environment, or with medications or personal habits of the worker to produce health effects even if the occupational exposures are controlled at the level set by the criterion. These combined effects are often not considered in the evaluation criteria. Also, some substances are absorbed by direct contact with the skin and mucous membranes, and thus potentially increase the overall exposure. Finally, evaluation criteria may change over the years as new information on the toxic effects of an agent become available.

The primary sources of environmental evaluation criteria for the workplace are: (1) NIOSH Recommended Exposure Limits (RELs)[a], (2) the American Conference of Governmental Industrial Hygienists' (ACGIH®) Threshold Limit Values (TLVs®)[b], and (3) the U.S. Department of Labor, Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PELs).[c] Employers are encouraged to follow the OSHA limits, the NIOSH RELs, the ACGIH TLVs, or whichever are the more protective criteria.

OSHA requires an employer to furnish employees a place of employment that is free from recognized hazards that are causing or are likely to cause death or serious physical harm [Occupational Safety and Health Act of 1970, Public Law 91–596, sec. 5(a)(1)]. Thus, employers should understand that not all hazardous chemicals have specific OSHA exposure limits such as PELs and short-term exposure limits (STELs). An employer is still required by OSHA to protect their employees from hazards, even in the absence of a specific OSHA PEL.

A time-weighted average (TWA) exposure refers to the average airborne concentration of a substance during a normal 8- to 10-hour workday. Some substances have recommended STEL or ceiling values, which are intended to supplement the TWA where there are recognized toxic effects from higher exposures over the short-term.

In contrast to the workplace, this situation outlined here is one in which the individuals were exposed to continuous, high concentrations of carbon dioxide in their home. No exposure standards currently exist for the home environment. The construction workers hired for the remediation were working in the home; therefore exposure limits do apply to them.

CARBON DIOXIDE

Carbon dioxide is a colorless, odorless gas that is a normal constituent of air. One percent carbon dioxide is equivalent to 10,000 ppm. Indoor carbon dioxide concentrations are normally higher than the ambient, outdoor carbon dioxide concentration, which ranges from 0.03 percent to 0.035 percent (300 – 350 ppm). The American Society for Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE) Standard 62-2001: Ventilation for Acceptable Indoor Air Quality, recommends a carbon dioxide concentration differential of no more than 0.07 percent (700 ppm), in relation to the outside air, which is a comfort (odor) criteria related to human bioeffluents.[d] Because no evaluation criteria exist for homes, NIOSH used workplace values to assess the hazard. The NIOSH REL and OSHA PEL for carbon dioxide is 0.5 percent (5,000 ppm) as a TWA. NIOSH also has a 15-minute STEL of 3 percent (30,000 ppm). The Immediately Dangerous to Life and Health (IDLH) value is 4 percent (40,000 ppm), which is based on acute inhalation toxicity data in humans.[e] The health effects of high carbon dioxide exposures include an increased breathing rate at 2 to 4 percent; increased blood pressure and dizziness at 4 to 6 percent; tremor, vision, and hearing problems at 6-10 percent; and drowsiness, unconsciousness, convulsions, coma, and death above 10 percent.[f]

OXYGEN

Oxygen is a normal constituent of the air at approximately 20.9 percent. Oxygen levels below 19.5 percent are considered oxygen-deficient and unsafe. At 15 percent oxygen, fire will extinguish due to a lack of sufficient oxygen.[g] At 17 percent, one may notice faster and deeper breathing along with a possible impaired judgment. Generally, at levels between 16.5 and 21 percent, most people are asymptomatic. At 16 percent, the first signs of hypoxia appear. From 12 to 16 percent, humans may note a rapid breathing and pulse, along with impaired muscular coordination. From 10 to 15 percent, emotional lability, exhaustion, and headache may develop. Nausea, vomiting, lethargy, and unconsciousness may transpire at levels ranging from 6 to 10 percent oxygen. Below 6 percent, convulsions, apnea, and cardiac arrest may occur.[h,i]

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TABLES AND FIGURES

Table 1. Carbon Dioxide and Oxygen Concentrations.

Date	Sample Site	CO_2 (%)	O_2 (%)
12/3/2003[1]	Crawlspace Air	NS[2]	14
	First Floor Air	~0.5[3, 4]	NS
	Basement Air	~1[4]	<19.5[5]
12/9/2003[6]	Between drywall and foundation	0.45	NS
	Crawlspace Air	1	20.4
12/10/2003	Crawlspace Air	9.5	14
	Floor drain (basement)[7]	12	12.5
	Crawlspace Ground Gas	11	14
	Ground Gas next to Front of House (outside)	8	NS
12/12/2003	Crawlspace Air	0.8	20.6
	Drainage Pipe Air (outside)	1.6	NS
	First Floor Air	0.1	NS
12/19/2003	Ground Gas next to Front of House (outside)	0.9	NS
	Crawlspace Seam of Membrane and Concrete Block[8]	2.8	NS
	Crawlspace Ground Gas Beneath Membrane #1	1.4	NS
	Crawlspace Ground Gas Beneath Membrane #2	3.2	NS
	Crawlspace Air	0.4	NS

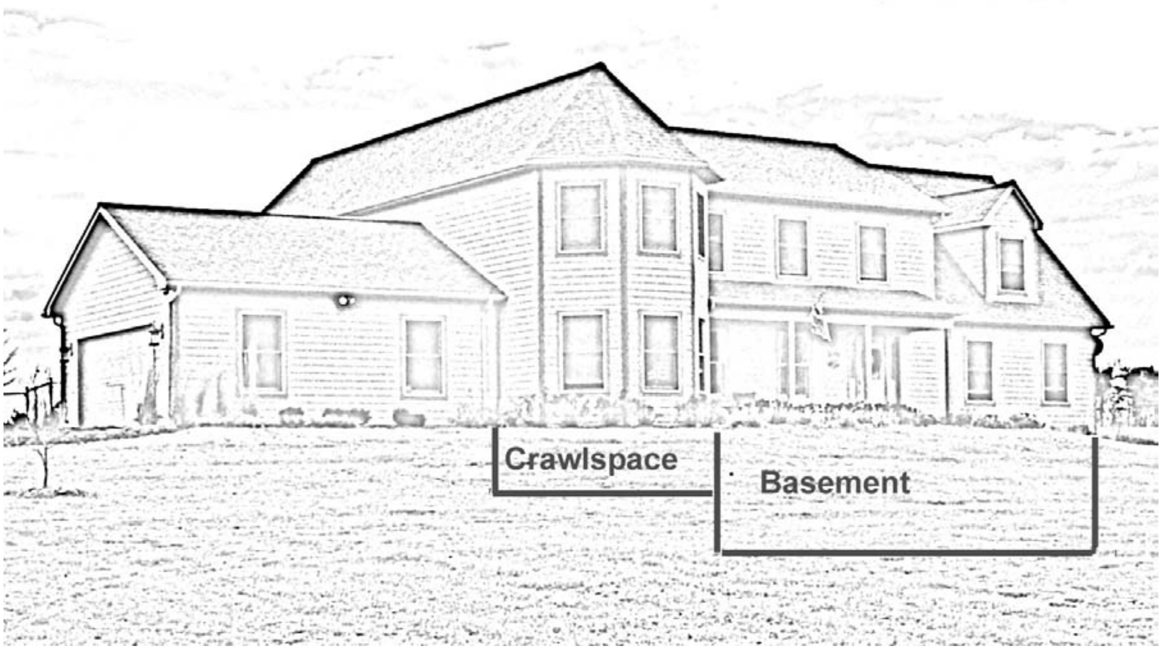
[1] After one day of natural ventilation through open windows
[2] NS – Not sampled
[3] ~ means "approximately"
[4] On December 3, 2003, two types of carbon dioxide monitors were available, with maximum limits of detection of 0.5 percent and 1 percent. The levels could have been higher than what was detected by these two monitors.
[5] Oxygen meter alarmed at 19.5 percent and investigators evacuated the basement.
[6] After one week of natural ventilation through open windows and initial remediation efforts consisting of sealing cracks in the foundation, removing cinder blocks from crawlspace, and placing a large fan outside the crawlspace for ventilation.
[7] Homeowners used oil in the floor drain that connects to the French drain system to seal the drain and keep carbon dioxide from entering the basement.
[8] Rubber membrane covering crawlspace gravel used for remediation of crawlspace area.

Table 2. Chemical Composition of the Air.

Component	Crawlspace[1] (mol. %)[2]	Drainage Pipe[3] (mol. %)
Argon	0.858	0.903
Oxygen	13.59	19.60
Nitrogen	76.80	78.67
Carbon dioxide	8.75	0.83

[1] Ground gas sample taken December 19, 2003.
[2] Mol % is approximately equivalent to volume percent.
[3] Air sample from underground mine water drainage pipe taken December 23, 2003. This sample was not taken on December 19th because the drainage pipe sample was very low that day. Higher carbon dioxide concentrations discharged from the drainage pipe on December 23rd.

Figure 1. Schematic of the home showing the basement and adjacent crawlspace.



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