CHAPTER 3 Landfill Gas Safety and Health Issues

This chapter provides information about health and safety issues associated with landfill gas—specifically, possible explosion and asphyxiation hazards and issues related to odors emanating from the landfill and low-level chemical emissions. It also contains information about health and safety issues associated with landfill fires (which may or may not be the direct result of landfill gas). This chapter also describes the tools that can be used to help environmental professionals respond to community health concerns. It provides information about what is known and unknown about the short-term and long-term health effects associated with landfill gas emissions, which can be mixtures of hundreds of different gases.

When reading this chapter, keep in mind that if people are not being exposed to landfill gases, no adverse health effects are expected. Exposures occur only if the landfill is producing harmful levels of gases *and* if the gases are migrating from the landfills *and* reaching people. Responding to community concerns about the possible health impacts of known or potential landfill gas emissions can often be difficult. Data (at the point of exposure) are needed to fully evaluate exposures, and these data are often limited or not available (see Chapter Four).

How are people exposed to landfill gas?

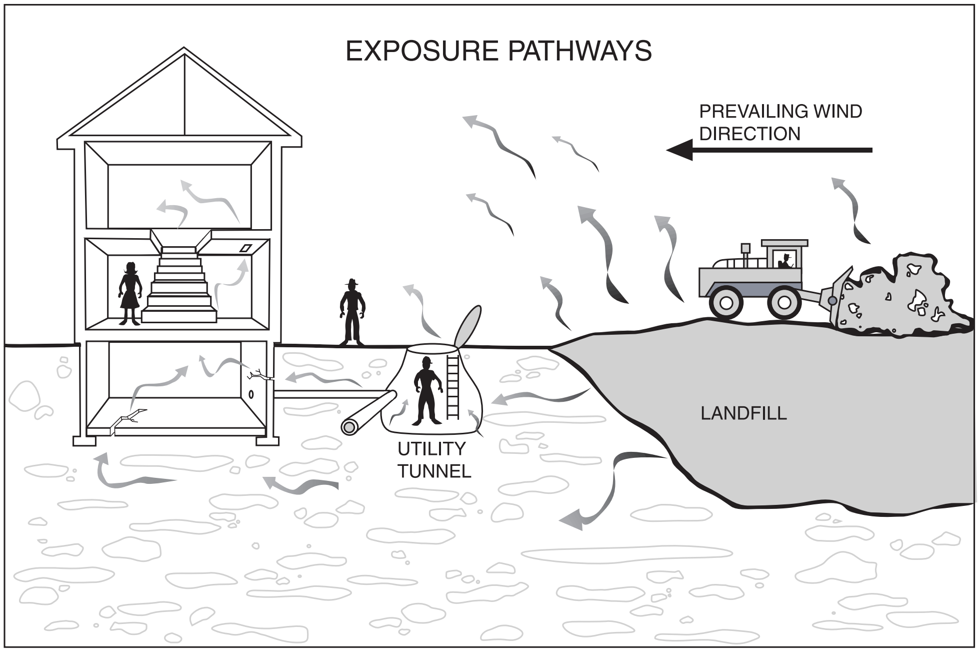
People may be exposed to landfill gases either at the landfill or in their communities. As discussed in Chapter Two, landfill gases may migrate from the landfill either above or below ground. Gases can move through the landfill surface to the ambient air. Once in the air, the landfill gases can be carried to the community with the wind. Odors from day-to-day landfill activities are indicative of gases moving above ground. Gases may also move through the soil underground and enter homes or utility corridors on or adjacent to the landfill. Figure 3-1 illustrates the movement of landfill gases and potential exposure pathways. The levels of gases that migrate from a landfill and to which people are exposed are dependent on many factors, as described in Chapter Two. Landfill gas collection and control systems have the greatest impact on gas migration and exposures. If a collection or control system is in place and operating properly, migration and exposures should be minimal.

Explosion Hazards

Landfill gas may form an explosive mixture when it combines with air in certain proportions. This section provides information about:

- The conditions that must be met for landfill gas to pose an explosion hazard.
- The types of gases that may potentially pose explosion hazards.
- What can be done to assess whether a landfill is posing an explosion hazard.

Figure 3-1: Potential Exposure Pathways to Landfill Gas



When does landfill gas pose an explosion hazard?

The following conditions must be met for landfill gas to pose an explosion hazard:

- ***Gas production.*** A landfill must be producing gas, and this gas must contain chemicals that are present at explosive levels.
- ***Gas migration.*** The gas must be able to migrate from the landfill. Underground pipes or natural subsurface geology may provide migration pathways for landfill gas (see Chapter Two, "What factors affect landfill gas migration?"). Gas collection and treatment systems, if operating properly, reduce the amount of gas that is able to escape from the landfill. (See Chapter Five.)
- ***Gas collection in a confined space.*** The gas must collect in a confined space to a concentration at which it could potentially explode. A confined space might be a manhole, a subsurface space, a utility room in a home, or a basement. The concentration at which a gas has the potential to explode is defined in terms of its lower and upper explosive limits (LEL and UEL), as defined at right.

Lower and Upper Explosive Limits (LEL and UEL)
The concentration level at which gas has the potential to explode is called the explosive limit. The potential for a gas to explode is determined by its lower explosive limit (LEL) and upper explosive limit (UEL). The LEL and UEL are measures of the percent of a gas in the air by volume. At concentrations below its LEL and above its UEL, a gas is *not* explosive. However, an explosion hazard may exist if a gas is present in the air between the LEL and UEL and an ignition source is present.

Landfill Gas Explosions

Although landfill gas explosions are by no means common occurrences, a number of incidents known or suspected to have been caused by landfill gas explosions have been documented.

1999	An 8-year-old girl was burned on her arms and legs when playing in an Atlanta playground. The area was reportedly used as an illegal dumping ground many years ago. (Atlanta Journal-Constitution 1999)
1994	While playing soccer in a park built over an old landfill in Charlotte, North Carolina, a woman was seriously burned by a methane explosion. (Charlotte Observer 1994)
1987	Off-site gas migration is suspected to have caused a house to explode in Pittsburgh, Pennsylvania. (EPA 1991)
1984	Landfill gas migrated to and destroyed one house near a landfill in Akron, Ohio. Ten houses were temporarily evacuated. (EPA 1991)
1983	An explosion destroyed a residence across the street from a landfill in Cincinnati, Ohio. Minor injuries were reported. (EPA 1991)
1975	In Sheridan, Colorado, landfill gas accumulated in a storm drain pipe that ran through a landfill. An explosion occurred when several children playing in the pipe lit a candle, resulting in serious injury to all the children. (USACE 1984)
1969	Methane gas migrated from an adjacent landfill into the basement of an armory in Winston-Salem, North Carolina. A lit cigarette caused the gas to explode, killing three men and seriously injuring five others. (USACE 1984)

See the box above for a few of many documented situations where all the conditions for explosions were met and explosions actually occurred.

What types of gases can pose an explosion hazard?

- ***Methane.*** Methane is the constituent of landfill gas that is likely to pose the greatest explosion hazard. Methane is explosive between its LEL of 5% by volume and its UEL of 15% by volume. Because methane concentrations within the landfill are typically 50% (much higher than its UEL), methane is unlikely to explode within the landfill boundaries. As methane migrates and is diluted, however, the methane gas mixture may be at explosive levels. Also, oxygen is a key component for creating an explosion, but the biological processes that produce methane require an anaerobic, or oxygen-depleted, environment. At the surface of the landfill, enough oxygen is present to support an explosion, but the methane gas usually diffuses into the ambient air to concentrations below the 5% LEL. In order to pose an explosion hazard, methane must migrate from the landfill and be present between its LEL and UEL.
- ***Other landfill gases.*** Other landfill gas constituents (e.g., ammonia, hydrogen sulfide, and NMOCs) are flammable. However, because they are unlikely to be present at concentrations above their LELs, they rarely pose explosion hazards as individual gases. For example, benzene (an NMOC that may be found in landfill gas) is explosive between its

LEL of 1.2% and its UEL of 7.8%. However, benzene concentrations in landfill gas are very unlikely to reach these levels. If benzene were detected in landfill gas at a concentration of 2 ppb (or 0.0000002% of the air by volume), then benzene would have to collect in a closed space at a concentration 6 million times greater than the concentration found in the landfill gas to cause an explosion hazard.

Table 3-1 summarizes the potential explosion hazards posed by the important constituents of landfill gas. Keep in mind that methane is the most likely landfill gas constituent to pose an explosion hazard. Other flammable landfill gas constituents are unlikely to be present at concentrations high enough to pose an explosion hazard. However, the flammable NMOCs do contribute to total explosive hazard when combined with methane in a confined space.

Table 3-1: Potential Explosion Hazards from Common Landfill Gas Components

Component	Potential to Pose an Explosion Hazard
Methane	Methane is highly explosive when mixed with air at a volume between its LEL of 5% and its UEL of 15%. At concentrations below 5% and above 15%, methane is not explosive. At some landfills, methane can be produced at sufficient quantities to collect in the landfill or nearby structures at explosive levels.
Carbon dioxide	Carbon dioxide is not flammable or explosive.
Nitrogen dioxide	Nitrogen dioxide is not flammable or explosive.
Oxygen	Oxygen is not flammable, but is necessary to support explosions.
Ammonia	Ammonia is flammable. Its LEL is 15% and its UEL is 28%. However, ammonia is unlikely to collect at a concentration high enough to pose an explosion hazard.
NMOCs	Potential explosion hazards vary by chemical. For example, the LEL of benzene is 1.2% and its UEL is 7.8%. However, benzene and other NMOCs alone are unlikely to collect at concentrations high enough to pose explosion hazards.
Hydrogen sulfide	Hydrogen sulfide is flammable. Its LEL is 4% and its UEL is 44%. However, in most landfills, hydrogen sulfide is unlikely to collect at a concentration high enough to pose an explosion hazard.

How can I assess whether a landfill in my community poses an explosion hazard?

The checklist on the following page can help determine if a landfill may pose an explosion hazard. If your evaluation identifies the potential for an explosion, several actions can be taken to prevent harm to the community. Measures and controls to prevent explosion hazards are discussed in Chapter Five. Possible public health actions are described in Appendix B.

Landfill Gas Explosion Hazard Checklist

- ❑ **Is the landfill producing gas and, if so, how much?**
  Because methane and carbon dioxide are the main components of landfill gas and these chemicals are both odorless and colorless, monitoring data are necessary to answer this question. (See Chapter Four for information about how landfill gas is monitored.)

- ❑ **Is a landfill gas collection system in place?**
  Landfill gas collection systems reduce levels of gas migrating from the landfill to surrounding areas. (See Chapter Five for information about collection systems.)

- ❑ **Is gas migrating from the landfill?**
  Off-site monitoring data may be necessary to answer this question. (See Chapter Four.)

- ❑ **If gas is migrating from the landfill and reaching structures, are there places for gas to collect?**
  Uncontrolled gases escaping from a landfill may migrate to structures on the landfill itself or in the surrounding area. However, the further a structure is from the landfill, the less likely it is that gases are migrating to it at concentrations great enough to pose an explosion threat. The most common places for gases to collect are basements, crawl spaces, or buried utility entry ports. Homes with basements, especially those with pipes or cracks in the basement that would allow gas to enter, are more likely to collect gases.

- ❑ **Is gas collecting at concentrations that are high enough to pose an explosion hazard?**
  Monitoring data are needed to answer this question. Caution should be used in selecting sampling equipment to ensure that an ignition source is not introduced into the area. (See Chapter Four for information about monitoring.)

- ❑ **Is there an ignition source?**
  Gases can be ignited by many different sources, such as a furnace in the basement or a pilot light on a gas stove. Other sources may include candles, matches, cigarettes, or a spark. Because there are so many ignition sources, it is safest to assume that the potential for an ignition source is always present.

Asphyxiation Hazards

Landfill gas poses an asphyxiation hazard only if it collects in an enclosed space (e.g., a basement or utility corridor) at concentrations high enough to displace existing air and create an oxygen-deficient environment. The Occupational Safety and Health Administration (OSHA) defines an oxygen-deficient environment as one that has less than 19.5% oxygen by volume (OSHA n.d.a). Ambient air contains approximately 21% oxygen by volume. Health effects associated with oxygen-deficient environments are described in Table 3-2.

Any of the gases that comprise landfill gas can, either individually or in combination, create an asphyxiation hazard if they are present at levels sufficient to create an oxygen-deficient environment.

Carbon dioxide, which comprises 40% to 60% of landfill gas, may pose specific asphyxiation hazard concerns. Because it is denser than air, carbon dioxide that has escaped from a landfill and collected in a confined space, such as a basement or an underground utility corridor, may remain in the area for hours or days after the area has been opened to the air (e.g., after a man-

Table 3-2: Health Effects from Oxygen-deficient Environments	
Oxygen Concentration	**Health Effects**
21%	Normal ambient air oxygen concentration
17%	Deteriorated night vision (not noticeable until a normal oxygen concentration is restored), increased breathing volume, and accelerated heartbeat
14% to 16%	Increased breathing volume, accelerated heartbeat, very poor muscular coordination, rapid fatigue, and intermittent respiration
6% to 10%	Nausea, vomiting, inability to perform, and unconsciousness
Less than 6%	Spasmatic breathing, convulsive movements, and death in minutes

Source: OSHA n.d.b

hole cover has been removed or a basement door opened). Carbon dioxide is colorless and odorless and therefore not readily detectable. Carbon dioxide concentrations of 10% or more can cause unconsciousness or death. Lower concentrations may cause headache, sweating, rapid breathing, increased heartbeat, shortness of breath, dizziness, mental depression, visual disturbances, or shaking. The seriousness of these symptoms depends on the concentration and duration of exposure. The response to carbon dioxide inhalation varies greatly even in healthy normal individuals.

In assessing the public health issues of migrating landfill gas, environmental health professionals should investigate the presence of buried utility lines and storm sewers on or adjacent to the landfill. These structures not only provide a pathway for migrating gases, but also pose a special asphyxiation problem for utility workers who fail to follow confined space entry procedures prescribed by OSHA. On-site or adjacent residences and commercial buildings with basements or insulated (or sealed) crawl spaces should also be investigated for potential asphyxiation hazards.

Health Issues Associated with Landfill Gas Emissions

Landfill odors often prompt complaints from community members. People may also have concerns about health effects associated with these odors and other emissions coming from the landfill. This section contains information about

- Symptoms possibly triggered by landfill gas odors.
- What scientists know about the potential health effects of exposures to landfill gas emissions.
- How environmental health professionals can assess whether landfill gas emissions may be posing a health threat.

Can the presence of odors trigger symptoms?

People in communities near landfills are often concerned about odors emitted from landfills. They say that these odors are a source of undesirable health effects or symptoms, such as headaches and nausea. At low-level concentrations—typically associated with landfill gas—it is unclear whether it is the constituent itself or its odors that trigger a response. Typically, these effects fade when the odor can no longer be detected. The box below describes the biology behind detecting odors.

Landfill gas odors are produced by bacterial or chemical processes and can emanate from both active or closed landfills. These odors can migrate to the surrounding community. Potential sources of landfill odors include sulfides, ammonia, and certain NMOCs, if present at concentrations that are high enough. Landfill odors may also be produced by the disposal of certain types of wastes, such as manures and fermented grains.

- ***Sulfides.*** Hydrogen sulfide, dimethyl sulfide, and mercaptans are the three most common sulfides responsible for landfill odors. These gases produce a very strong rotten-egg smell—even at very low concentrations. Of these three sulfides, hydrogen sulfide is emitted from landfills at the highest rates and concentrations.

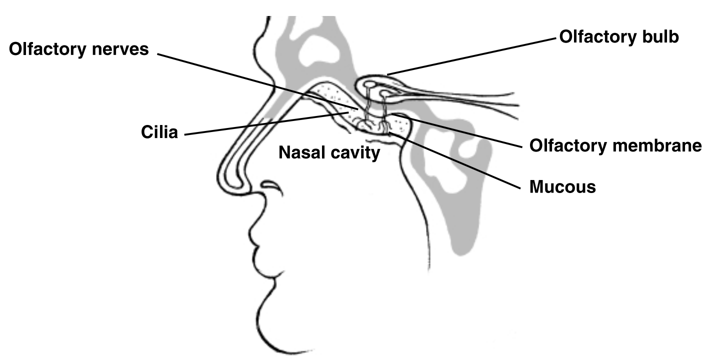
  Humans are extremely sensitive to hydrogen sulfide odors and can smell such odors at concentrations as low as 0.5 to 1 part per billion (ppb). At levels approaching 50 ppb, people can find the odor offensive. Average concentrations in ambient air range from 0.11 to 0.33 ppb (ATSDR 1999a). According to information collected by the Connecticut Department of Health, the concentration of hydrogen sulfide in ambient air around a landfill is usually close to 15 ppb (CTDPH 1997; ATSDR 1999a).

How Do People Detect Odors?

Humans can distinguish between 3,000 and 10,000 different odors. Although people commonly believe that they smell with their noses, the nose is only one part of the olfactory system that allows humans to distinguish smells. The nose serves as a vacuum that pulls in air and odorous chemicals, such as hydrogen sulfide. The air and odorous chemicals are warmed in the nasal cavity and then trapped in mucus surrounding the olfactory membrane. The olfactory membrane is an area smaller than 1 square inch located deep in the nasal cavity between the eyes. Odorous chemicals interact with receptors (chemoreceptors) found on small hairs (cilia) on the olfactory membrane. The receptors send messages about the odorous chemicals to the brain through the olfactory bulb. The brain then interprets and identifies the odor (Jacobs 1999).

The sense of smell, just like the other senses of sight, hearing, taste, and touch, varies from person to person. One person may be able to smell an odor like hydrogen sulfide at extremely low concentrations, while another person in the same community or home cannot. Because of this variation, there is no true odor threshold value above which odors are unpleasant and below which odors are not noticeable. Any odor threshold values reported in the literature, such as those provided in Table 3-3, are only estimates of concentrations that the average person may detect (AIHA 1989). Therefore, health professionals should be cautious when citing established threshold values or discussing them with community members.

Anatomy of Smell



LANDFILL GAS SAFETY AND HEALTH ISSUES

- ***Ammonia.*** Ammonia is another odorous landfill gas that is produced by the decomposition of organic matter in the landfill. Ammonia is common in the environment and an important compound for maintaining plant and animal life. People are exposed daily to low levels of ammonia in the environment from the natural breakdown of manure and dead plants and animals. Because ammonia is commonly used as a household cleaner, most people are familiar with its distinct smell.

  Humans are much less sensitive to the odor of ammonia than they are to sulfide odors. The odor threshold for ammonia is between 28,000 and 50,000 ppb. Landfill gas has been reported to contain between 1,000,000 and 10,000,000 ppb of ammonia, or 0.1% to 1% ammonia by volume (Zero Waste America n.d.). Concentrations in ambient air at or near the landfill site are expected to be much lower.

- ***NMOCs.*** Some NMOCs, such as vinyl chloride and hydrocarbons, may also cause odors. In general, however, NMOCs are emitted at very low (trace) concentrations and are unlikely to pose a severe odor problem.

Table 3-3 lists some of the common landfill gas components and their odor thresholds.

Many people may find the odors emitted from a landfill offensive or unpleasant. In reaction to the odor, some people may experience nausea or headaches. Although such responses are undesirable, medical attention is usually not required. Often, symptoms such as headaches and nausea fade when the odor goes away. However, the effects on day-to-day life can be more lasting. Families living close to a landfill in Connecticut described frequent odor events as overwhelmingly disruptive. One family reported being awakened during predawn hours by a flood of nauseating air that persisted for 2 or more hours. The loss of sleep and the frustration from the frequent odor events greatly added to the level of stress in the family's life. Although landfill odors may not associated with long-term adverse health effects or illness for most people, the added disruption and stress of day-to-day activities can greatly impact quality of life. The story below describes how environmental and health professionals addressed odor problems in Danbury,Connecticut.

Table 3-3: Common Landfill Gas Components and Their Odor Thresholds

Component	Odor Description	Odor Threshold (parts per billion)
Hydrogen Sulfide	Strong rotten egg smell	0.5 to 1
Ammonia	Pungent acidic or suffocating odor	1,000 to 5,000
Benzene	Paint-thinner-like odor	840
Dichloroethylene	Sweet, ether-like, slightly acrid odor	85
Dichloromethane	Sweet, chloroform-like odor	205,000 to 307,000
Ethylbenzene	Aromatic odor like benzene	90 to 600
Toluene	Aromatic odor like benzene	10,000 to 15,000
Trichloroethylene	Sweet, chloroform-like odor	21,400
Tetrachloroethylene	Sweet, ether- or chloroform-like odor	50,000
Vinyl Chloride	Faintly sweet odor	10,000 to 20,000

Sources: NTP n.d.; NJDHSS n.d.

The impact of landfill gas odors on sensitive populations such as people with pre-existing respiratory illnesses is not well documented or understood. A study conducted on Staten Island showed an increase in self-reported wheezing among asthmatics living near a landfill on days when they reported odors. Ambient air measurements, however, showed levels of hydrogen sulfide and other emissions much lower than levels known to be associated with adverse health effects (ATSDR 1999b). The box below provides more information about this study. The study suggests that odors in and of themselves may trigger respiratory effects among asthmatics. This preliminary conclusion may be confounded by other environmental triggers for respiratory response in asthmatics, such as dust mites, animal dander, tobacco smoke, and outdoor air pollution. The American Lung Association Web site (**http://www.lungusa.org/asthma/index.html**) provides more information about possible environmental triggers for asthma. EPA provides information about asthma itself at **http://www.epa.gov/children/asthma.htm** and **http://www.epa.gov/iaq/asthma/**.

The Danbury Landfill—One Community's Story

Danbury, Connecticut, is a community that successfully tackled a landfill odor problem. In the Spring of 1996, a 100-year-old landfill in Danbury caught fire. Water used to extinguish the fire promoted bacteria growth and increased the production of odor-causing sulfides, especially hydrogen sulfide.

The increase in odors prompted public concerns and questions. Though hydrogen sulfide levels in the air were well below concentrations that might affect human health, the odor caused nausea and headaches in some residents. Local and state health authorities and environmental agencies worked together to address the odor problem. They took the following actions to alleviate community concerns and address the odor problem:

- Landfill operators controlled sulfide releases and odors by adding lime as a short-term solution and by installing a fabric landfill liner, a gas collection system, and a flaring system as the long-term solution.
- Local health departments produced and distributed a newsletter to educate community members about landfill odors and what was being done to reduce them.
- Hydrogen sulfide concentrations were measured with monitoring devices located in areas where exposure might occur, such as nearby residential homes and retail areas. Concerned parties developed a four-tiered response plan based on measured hydrogen sulfide concentrations in the nearby community:

1. At concentrations greater than 100 ppb for 15 minutes, landfill operators would take immediate action to reduce emissions.
2. At concentrations greater than 100 ppb for 2 hours, medical personnel would be notified that sensitive individuals (e.g., children, elderly, or asthmatics) might be affected.
3. At concentrations greater than 500 ppb for 2 hours, sensitive individuals would be advised to stay indoors or leave the area.
4. At concentrations greater than 5,000 ppb for 30 minutes, all residents would be advised to leave the area.

The first action level was triggered a few times during the period when odor control measures were being installed. The other action levels were never triggered. Once odors were controlled, community complaints decreased markedly.

What do we know about the potential health effects of exposure to landfill gas?

Landfill gas constituents are typically found in ambient air at low concentrations unlikely to cause adverse health effects. However, whether landfill emissions pose a health hazard depends on the chemical concentrations to which people are being exposed and the duration of the exposure.

Fresh Kills Landfill—A Case Study

ATSDR conducted a health study of communities near the Fresh Kills Municipal Landfill in Staten Island, New York. The study was undertaken to gain a better understanding of the possible health risks posed by the landfill to residents in nearby communities. ATSDR designed the study to assess how hydrogen sulfide concentrations, odors, and proximity of residence to the landfill might affect respiratory function. The focus was on asthma.

A group of more than 150 community residents reported as having asthma volunteered to participate in the study. For a 6-week period in July through September 1997, when annual landfill emissions tend to be at their peak, study participants completed a daily diary to record perceived odors, respiratory symptoms, and daily activities. Participants also measured their lung function each morning and evening with a peak expiratory flow meter. During this same period, ATSDR conducted continuous monitoring in the study area to assess ambient air concentrations of hydrogen sulfide, ozone, and particulate matter. Meteorologic data as well as pollen and fungi counts were collected; these are confounding factors that can trigger asthma. ATSDR also conducted a separate odor impact survey to provide an independent odor assessment around the landfill.

ATSDR concluded that the measured levels of hydrogen sulfide and other parameters were not high enough to cause adverse health effects. However, when study participants reported that they smelled rotten eggs or garbage, they also reported that they were more likely to wheeze or experience difficulties in breathing. A moderate decline in lung function was also documented on days when participants reported these odors. These results varied throughout the study group by factors such as the participant's age and how long he or she had suffered from asthma (ATSDR 1999b).

In addition to concerns about persistent landfill gas odors, people living near a landfill may be concerned about the health effects of exposures to the landfill gas mixture or specific landfill gas constituents, both in the short term and in the long term. As described below, odor-producing chemicals (i.e., hydrogen sulfide and ammonia) are not likely to produce long-term adverse health effects at the levels typically associated with landfill emissions. The odors associated with these chemicals can, however, cause acute (short-term) effects, such as nausea and headaches, as mentioned earlier. Acute effects from other chemicals found in landfill gas are usually produced only when an individual is exposed at relatively high concentrations (i.e., at concentrations greater than those expected to be present in ambient air near a landfill). Acute effects are usually reversed when the odor or exposure ends.

- ***Hydrogen sulfide.*** To date, researchers have not identified any long-term health effects associated with exposure to the low-level hydrogen sulfide concentrations that normally occur in communities near landfills. As mentioned previously, hydrogen sulfide concentrations in the air around a landfill are usually less than 15 ppb (CTDPH 1997). See the box below for more detailed information about the health effects associated with exposures to various concentrations of hydrogen sulfide. Figure 3-2 displays the health effects of hydrogen sulfide exposure at increasing concentrations.

- ***Ammonia.*** Studies of health effects resulting from exposure to ammonia have found that people who inhale 50,000 ppb of ammonia in the air for less than 1 day experience slight and temporary irritation. Irritation, therefore, begins at concentrations at or above the odor threshold. People exposed to 500,000 ppb for 30 minutes increase their air intake and report soreness of the nose and throat. Ammonia can be fatal when a person is exposed to 5,000,000 ppb for under 30 minutes. This concentration is equivalent to an atmosphere containing 0.5% ammonia. A study of chronic ammonia exposure found that people exposed to ammonia at a concentration of 100,000 ppb in air for more than 6 weeks experienced eye, nose, and throat irritation (ATSDR 1990). Concentrations of ammonia in the ambient air near a landfill are expected to be well below the levels at which any adverse health effects are expected to occur.
- ***NMOCs.*** The health effects of other landfill gas constituents, such as NMOCs, need to be considered on a chemical-by-chemical basis. It is also important to consider their

What Do Scientists Know About the Health Effects of Hydrogen Sulfide?

Researchers have studied both animal and human subjects (including asthma sufferers) to learn about possible health effects resulting from exposure to varying concentrations of hydrogen sulfide. Bear in mind that concentrations of hydrogen sulfide in the ambient air near a landfill are expected to be well below the levels at which any long-term illnesses expected to occur; however, acute symptoms may occur as a result of the strong odor associated with hydrogen sulfide.

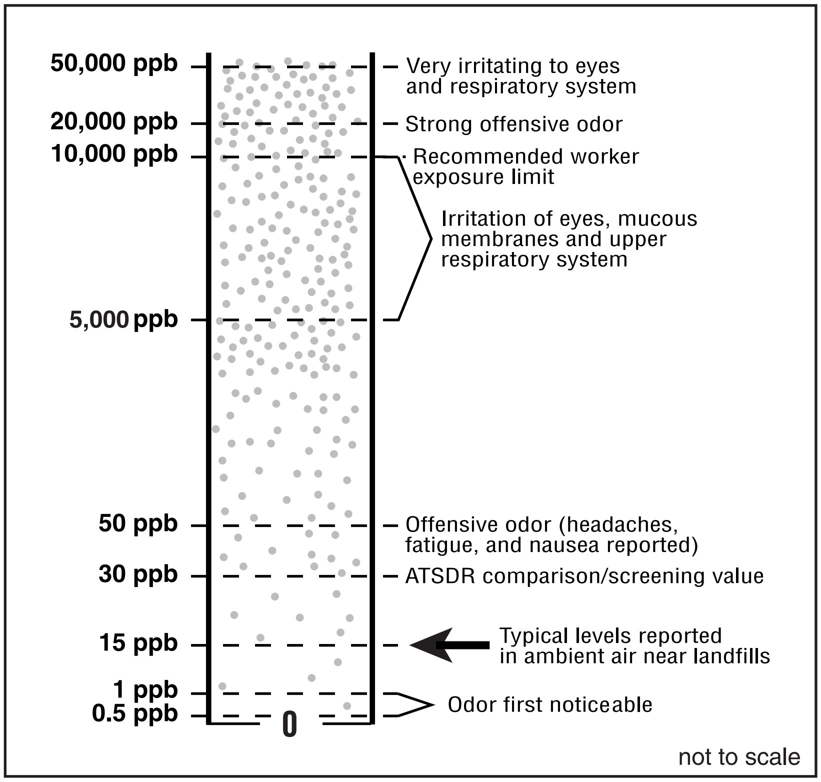
Experimental animal studies have generally found that hydrogen sulfide does not cause harm at levels as high as 5,000 ppb. Studies of pregnant mice with daily exposures of up to 20,000 ppb concluded that hydrogen sulfide does not alter fetal development. One study showed no effects at levels up to 150,000 ppb (ATSDR 1999a).

In two laboratory studies of human subjects, healthy persons experienced no significant health effects when exposed to hydrogen sulfide concentrations of up to 5,000 ppb. Some blood chemistry levels were affected, but the ability of the subjects to function was not hampered (Bhambhani et al. 1996, 1997).

Other studies examined human exposure at workplaces such as animal-processing or sewage treatment plants, where concentrations of hydrogen sulfide are much higher than those expected to be encountered in communities. These studies found that eye irritation is the first symptom reported, and irritation usually does not occur until hydrogen sulfide concentrations reach 5,000 to 10,000 ppb. At levels from 10,000 to 50,000 ppb, people have reported severe eye and respiratory irritations. Symptoms usually end when the concentrations decrease or exposures stop. At very high concentrations (above 500,000 ppb), hydrogen sulfide can be fatal. These high concentrations are likely to be found only in enclosed spaces with limited ventilation, such as storage tanks or silos (ATSDR 1999a).

Studies of asthma sufferers have shown no significant health effects at concentrations as high as 2,000 ppb. Some asthmatics have shown mild bronchial restriction at 2,000 ppb. Epidemiologic studies of asthma sufferers and workers in pulp mills (another common source of hydrogen sulfide) did not identify any significant health effects from exposure to hydrogen sulfide concentrations in the air (Jäppinen et al. 1990; Rossi et al. 1993).

Figure 3-2: Odor Thresholds and Health Effect Levels of HydrogenSulfide



Source: ATSDR 1999a

possible cumulative effects. In general, levels of individual landfill gases in ambient air are not likely to reach harmful levels. In other words, low levels of landfill gases are unlikely to cause obvious, immediate health effects. However, the potential health effects from long-term exposures to low levels of landfill gases released to ambient air are not easy to evaluate, largely because exposure data are often lacking.

Many exposures to landfill gas involve chemicals at low or trace levels, as well as mixtures of chemicals. Most studies that look at health effects from chemical exposures consider much higher chemical exposures levels than those associated with landfills. Only a small number of studies have looked at low-level, multi-chemical exposures. The handful of studies looking at possible long-term adverse health effects (e.g., cancer) associated with low-level and multi-chemical exposures associated with living near landfills have been largely inconclusive. Appendix C contains summaries of five such studies. Although each study found some increase in reproductive effects or cancer incidence, overall, the data were inconclusive. In each study, the researchers noted the lack of data both about specific landfill gas emissions and about the effects of confounding factors such as lifestyle choices that may affect the health of individuals exposed to landfill gas emissions. Investigators noted that a study of a single landfill and the surrounding community is unlikely to answer the question of whether landfill gases are adversely affecting the health of community members. In all cases, the investigators cited the need for additional studies.

How can environmental health professionals assess whether landfill gas emissions may be posing a health threat?

If landfill gas or ambient air monitoring data are available for the landfill, a first step in assessing potential health hazards would be to compare detected concentrations against available screening values. In doing so, it is important to consider exposure point concentrations (i.e., What are the concentrations in the air that people are breathing?). Unfortunately, ambient air data are rarely available (especially in areas neighboring a landfill).

Landfill gas data can help rule out problems (i.e., if landfill gas readings are below screening levels, concentrations in ambient air will be even lower). Landfill gas data can also be used in mathematical models that predict concentrations in ambient air. But without measured ambient air data, it is difficult to determine the extent to which elevated landfill gas readings might be affecting ambient air. (See Chapter Four for information about how landfill gas is monitored, how to evaluate the adequacy and representativeness of data, and how models can be used to predict ambient air concentrations.)

Note: When comparing available landfill gas or ambient monitoring data to screening values, it is important to pay close attention to the units in which the chemicals were measured. Air concentrations are typically reported as concentrations per volume (e.g., milligrams per cubic meter [mg/m^3] or micrograms per cubic meter [$\mu g/m^3$]) or as concentrations per mass (e.g., ppm or ppb).

To convert a concentration (C) in $\mu g/m^3$ to a concentration in ppb, the following equation should be used:

$$C\ (\mu g/m^3) = \frac{C\ (\text{ppb}) \times \text{molecular weight (grams/mole)}}{24.45}$$

Both ATSDR and EPA have developed screening values to evaluate air exposures. These screening values have been conservatively derived from experimental (animal) and human studies. ATSDR's minimal risk levels (MRLs) can be found on the web at **http://www.atsdr.cdc.gov/mrls.html**. EPA's risk-based concentrations (RBCs) can be found at **http://www.epa.gov/reg3hwmd/risk/riskmenu.htm**. EPA's human health medium-specific screening values can be found at **http://www.epa.gov/earth1r6/6pd/rcra_c/pd-n/screen.htm**. In addition, many states have developed health-based air standards or guidelines.

These screening values consider sensitive effects and often apply uncertainty factors to account for the lack of knowledge about toxic effects and human variability.[1] Screening values can therefore be much lower than levels at which adverse health effects have actually been observed in studies. Depending on the chemical, screening values may be available to assess both short-term (acute) and long-term (chronic) effects and exposures.

If chemicals detected in landfill gas or air surrounding the landfill are below chemical-specific screening values, adverse health effects are unlikely. If chemicals are detected above screening values, it does not necessarily indicate that adverse health effects would be expected in a community, but that further evaluation is necessary. Site-specific exposures need to be closely exam

[1]ATSDR's MRLs look at noncancer effects. EPA's RBCs and some state guidelines may also consider possible cancer effects.

ined and chemical-specific information should be researched to assist the community with understanding what is known about these possible exposures.

Information about chemical-specific toxicity is available through a variety of sources. ATSDR's toxicological profiles, for example, provide a summary of health studies for a chemical and provide an overall perspective of the chemical's toxicity. ATSDR ToxFAQs briefly describe key chemical-specific health issues (**http://www.atsdr.cdc.gov/toxfaq.html**.) Other on-line sources of toxicologic information include the National Library of Medicine's Medline (**http://www.nlm.nih.gov/hinfo.htm**) or TOXNET (**http://toxnet.nlm.nih.gov/**) and EPA's Integrated Risk Information System (IRIS) (**http://www.epa.gov/iris/**).

If monitoring data indicate that elevated concentrations of landfill gas are entering a community and that the landfill gases could plausibly be linked with adverse health effects, immediate public actions should be taken to prevent or reduce human exposure, and a site-specific health study could be considered.

Landfill Fires

Landfill fires may or may not be directly caused by landfill gas; however, because of the potential health and safety issues that they pose (e.g., gases released during the fire), this primer provides information about landfill fires.

If conditions are right, landfill fires can burn underground. Underground fires are extremely difficult to combat and can burn for days or even weeks. The heat from the fire can cause chemicals to volatilize or break down and enter the environment. Consumer products in a landfill are the most likely source of chemical releases; these products may include pesticides, paints, solvents, cleaners, or chemical additives. These chemicals may be released in smoke from the fire.

Currently, no scientific publications are available that address health effects from inhaling smoke produced during landfill fires. In order to answer concerns about potential health effects of smoke, a health professional can evaluate potential health effects posed by the particulate matter and individual chemicals emitted during the fire. It is important to note, however, that although a single chemical in the smoke may not be present in concentrations that are high enough to cause health effects, the effects of a combination of chemicals may produce unknown health reactions. Ambient air sampling and monitoring data from the community can most accurately identify the contaminants being released during the fire.

Public health and environmental professionals may be called on to develop responses for preventing or reducing community exposures to landfill fire smoke and emissions. Guidance on landfill fires developed by ATSDR describes possible responses (a copy of this guidance is provided in Appendix B). The guidance describes action levels that can be developed, using monitoring data along with assumptions about the fire's duration. The action levels are then used as triggers for measures to protect public health. For example, at certain particulate matter or chemical concentrations, the guidance recommends that people remain indoors and close windows and doors. The guidance also states that if the concentration increases, it may be appropriate to evacuate people within a certain radius of the landfill.

Additional Resources

The American Lung Association. **http://www.lungusa.org/asthma/index.html**.

ATSDR. **http://www.atsdr.cdc.gov**.

ATSDR Exposure Investigation: Hydrogen Sulfide in Ambient Air, Dakota City/South Sioux City, Nebraska: **http://www.atsdr.cdc.gov/HAC/PHA/dakcity/dak_toc.html**.

EPA. Climate Change, Methane and Other Greenhouse Gases. **http://www.epa.gov/ghginfo/**.

EPA. Integrated Risk Information System (IRIS). **http://www.epa.gov/iris/**.

National Library of Medicine. MEDLINE/PubMed. **http://www.ncbi.nlm.nih.gov/entrez/query.fcgi**.

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