Landfill Gas Primer

An Overview for Environmental Health Professionals

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ATSDR
AGENCY FOR TOXIC SUBSTANCES
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Preface

Disposal of household and light industrial and commercial wastes is a necessity. Although there are several technologies available to handle these wastes, the most common means of disposal remains the municipal solid waste (MSW) landfill. With thousands of MSW landfills across the nation, it is not surprising that over the past 15 years, the Agency for Toxic Substances and Disease Registry (ATSDR) has received many requests for technical assistance and consultation about landfill issues. One of the most common requests is to evaluate the public health implications of landfill gas releases.

Landfill gas releases may represent physical (explosion), chemical (substances in ambient or indoor air), and/or physiologic or quality of life (odor) public health concerns for those who live and work near (or on) a landfill. This primer is intended to provide the environmental health professional, as well as the interested community member, with a basic understanding of landfill gases and how they should be viewed and evaluated from a public health perspective. It provides answers to questions that ATSDR has received from federal agencies, tribes, state and local health departments, and communities. Although the primer is thorough, the practical and applied guidance provided should be used to augment, and not replace, the multidisciplinary evaluation of public health issues related to landfill gas releases. Collaboration among the health and environmental entities and the community or tribe is necessary to address these issues. Such collaboration requires effective communication; the primer places special emphasis on communication as the key to successful implementation of any public health action or intervention.

Generally, well-maintained and operated MSW landfills will not be of public health concern or a nuisance to nearby neighbors. However, because much is left to be learned about the health effects that may result from exposures to low levels of ambient air contaminants and mixtures of these contaminants, environmental health professionals should exert care when assessing landfill gas issues. Several health studies are abstracted in this document to indicate the limited epidemiologic knowledge currently available to assist the environmental health professional in making public health decisions. The guidance and checklists are intended to prompt the health investigator to ask questions that shed light on the complexity of factors impacting the fate and transport of, and ultimately exposures to, landfill gases.

Our desire is for this primer to be a valuable resource for those who have questions and those who address questions about landfill gas releases. Your feedback to ATSDR will be helpful in defining what future guidance or revision is needed as we continue to address the myriad of public health questions that arise from the release of toxic and hazardous materials into the environment.

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CHAPTER

1

Introduction

This primer is designed to provide environmental health professionals with a general understanding of landfill gases and to help them in responding to community concerns that may be related to landfill gas issues. It provides basic information about the composition, formation, and movement of landfill gas. The primer also discusses health and safety issues related to landfill gas, and it provides information about landfill gas monitoring methods and control measures. Finally, the primer presents some basic guidance on how to communicate information about landfill gas issues.

This document incorporates information on landfills and landfill gases from a variety of sources, such as the U.S. Environmental Protection Agency (EPA), the U.S. Army Corps of Engineers, the California Air Resources Board, the Solid Waste Association of North America (SWANA), the Missouri Department of Natural Resources, and many professional publications. Among these, a valuable source of information is the insight and experience of the environmental health professionals working for the Agency for Toxic Substances and Disease Registry (ATSDR) and its state partners, such as the Connecticut Department of Health, the Minnesota Department of Health, and the New Hampshire Department of Health. Since 1985, environmental health scientists and engineers of ATSDR and state agencies have investigated hundreds of closed and operating landfills listed on EPA's National Priorities List (Superfund site list) or otherwise identified as a result of community concern.

This document was prepared in response to the many inquiries from environmental health professionals about landfill gas issues. Residents, local officials, and environmental regulators frequently request the assistance of ATSDR and local and state health departments in evaluating landfill gas problems. The following chapters cover many of the topics and issues that environmental health professionals are often called upon to address.

- ***Chapter Two*** contains basic information about landfill gas—what it is composed of, how it is formed, and the conditions that affect its production. It also provides information about how landfill gas moves and travels away from the landfill site.
- ***Chapter Three*** provides information about the health and safety issues associated with landfill gas—specifically, issues related to possible explosion and asphyxiation hazards, odors, 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).

- ***Chapter Four*** provides an overview of landfill gas monitoring, which may be conducted to fulfill regulatory requirements or to investigate environmental or health concerns. The chapter provides information about landfill gas sampling and monitoring program design, sampling and monitoring equipment, and interpretation of sampling and monitoring results.
- ***Chapter Five*** contains some information about landfill gas control technologies that might be employed to meet regulatory requirements, abate odor problems, or address potential health or safety concerns. The chapter describes regulatory requirements for landfill gas control, components of a landfill gas control plan, and options available to collect and treat or reuse landfill gas.
- ***Chapter Six*** presents some general guidelines on communicating landfill gas issues to people who live or work near a landfill. Information in the chapter can help environmental health professionals respond to questions and concerns about landfill gas and develop a proactive approach to informing and involving all who have a stake in addressing landfill gas issues.

Appendix A provides a list of the acronyms used throughout this document. This primer also includes appendices that provide ATSDR guidelines ***(Appendix B)***, summarize several health studies of exposure to landfill gas ***(Appendix C)***, describe a case study in which people were exposed to landfill gases ***(Appendix D)***, and provide examples of landfill gas fact sheets and a landfill gas sampling protocol ***(Appendix E)***.

Throughout the primer, references to supplementary sources of information can be found—such as Web sites, technical guidance documents, and scientific studies. These sources offer additional guidance at a greater level of detail. Experienced users of Internet resources are familiar with the problems of Web site references. Web site content and addresses change rapidly, making it very difficult to provide permanent references to this information. Therefore, the Web site references in this document are only as accurate as the date of the latest revision of the document.

The primer also refers the reader to applicable federal environment laws and regulations such as the Resource Conservation and Recovery Act (RCRA) and the Clean Air Act. However, the primer is not intended as a resource or reference for environmental regulations. Environmental laws, regulations, and guidelines change with legislative actions, court interpretations, and executive orders. Environmental health professionals are encouraged to contact the appropriate state or EPA staff to discuss the most up-to-date environmental laws and regulations applicable to landfill gas issues.

Mention of trade names, or commercial sources in this primer is for identification only and does not imply endorsement or recommendation for use by ATSDR or the U.S. Department of Health and Human Services.

CHAPTER 2

Landfill Gas Basics

This chapter provides basic information about landfill gas—what it is composed of, how it is produced, and the conditions that affect its production. It also provides information about how landfill gas moves and travels away from the landfill site. Finally, the chapter presents an overview of the types of landfills that might be present in your community and the regulatory requirements that apply to each.

What is landfill gas composed of?

Landfill gas is composed of a mixture of hundreds of different gases. By volume, landfill gas typically contains 45% to 60% methane and 40% to 60% carbon dioxide. Landfill gas also includes small amounts of nitrogen, oxygen, ammonia, sulfides, hydrogen, carbon monoxide, and nonmethane organic compounds (NMOCs) such as trichloroethylene, benzene, and vinyl chloride. Table 2-1 lists "typical" landfill gases, their percent by volume, and their characteristics.

How is landfill gas produced?

Three processes—bacterial decomposition, volatilization, and chemical reactions—form landfill gas.

- ***Bacterial decomposition.*** Most landfill gas is produced by bacterial decomposition, which occurs when organic waste is broken down by bacteria naturally present in the waste and in the soil used to cover the landfill. Organic wastes include food, garden waste, street sweepings, textiles, and wood and paper products. Bacteria decompose organic waste in four phases, and the composition of the gas changes during each phase. The box on page 5 provides detailed information about the four phases of bacterial decomposition and the gases produced during each phase. Figure 2-1 shows gas production at each of the four stages.
- ***Volatilization.*** Landfill gases can be created when certain wastes, particularly organic compounds, change from a liquid or a solid into a vapor. This process is known as volatilization. NMOCs in landfill gas may be the result of volatilization of certain chemicals disposed of in the landfill.
- ***Chemical reactions.*** Landfill gas, including NMOCs, can be created by the reactions of certain chemicals present in waste. For example, if chlorine bleach and ammonia come into contact with each other within the landfill, a harmful gas is produced.

Table 2-1: Typical Landfill Gas Components

Component	Percent by Volume	Characteristics
methane	45–60	Methane is a naturally occurring gas. It is colorless and odorless. Landfills are the single largest source of U.S. man-made methane emissions.
carbon dioxide	40–60	Carbon dioxide is naturally found at small concentrations in the atmosphere (0.03%). It is colorless, odorless, and slightly acidic.
nitrogen	2–5	Nitrogen comprises approximately 79% of the atmosphere. It is odorless, tasteless, and colorless.
oxygen	0.1–1	Oxygen comprises approximately 21% of the atmosphere. It is odorless, tasteless, and colorless.
ammonia	0.1–1	Ammonia is a colorless gas with a pungent odor.
NMOCs (non-methane organic compounds)	0.01–0.6	NMOCs are organic compounds (i.e., compounds that contain carbon). (Methane is an organic compound but is not considered an NMOC.) NMOCs may occur naturally or be formed by synthetic chemical processes. NMOCs most commonly found in landfills include acrylonitrile, benzene, 1,1-dichloroethane, 1,2-cis dichloroethylene, dichloromethane, carbonyl sulfide, ethylbenzene, hexane, methyl ethyl ketone, tetrachloroethylene, toluene, trichloroethylene, vinyl chloride, and xylenes.
sulfides	0–1	Sulfides (e.g., hydrogen sulfide, dimethyl sulfide, mercaptans) are naturally occurring gases that give the landfill gas mixture its rotten-egg smell. Sulfides can cause unpleasant odors even at very low concentrations.
hydrogen	0–0.2	Hydrogen is an odorless, colorless gas.
carbon monoxide	0–0.2	Carbon monoxide is an odorless, colorless gas.

Source: Tchobanoglous, Theisen, and Vigil 1993; EPA 1995

The Four Phases of Bacterial Decomposition of Landfill Waste

Bacteria decompose landfill waste in four phases. The composition of the gas produced changes with each of the four phases of decomposition. Landfills often accept waste over a 20- to 30-year period, so waste in a landfill may be undergoing several phases of decomposition at once. This means that older waste in one area might be in a different phase of decomposition than more recently buried waste in another area.

Phase I

During the first phase of decomposition, aerobic bacteria—bacteria that live only in the presence of oxygen—consume oxygen while breaking down the long molecular chains of complex carbohydrates, proteins, and lipids that comprise organic waste. The primary byproduct of this process is carbon dioxide. Nitrogen content is high at the beginning of this phase, but declines as the landfill moves through the four phases. Phase I continues until available oxygen is depleted. Phase I decomposition can last for days or months, depending on how much oxygen is present when the waste is disposed of in the landfill. Oxygen levels will vary according to factors such as how loose or compressed the waste was when it was buried.

Phase II

Phase II decomposition starts after the oxygen in the landfill has been used up. Using an anaerobic process (a process that does not require oxygen), bacteria convert compounds created by aerobic bacteria into acetic, lactic, and formic acids and alcohols such as methanol and ethanol. The landfill becomes highly acidic. As the acids mix with the moisture present in the landfill, they cause certain nutrients to dissolve, making nitrogen and phosphorus available to the increasingly diverse species of bacteria in the landfill. The gaseous byproducts of these processes are carbon dioxide and hydrogen. If the landfill is disturbed or if oxygen is somehow introduced into the landfill, microbial processes will return to Phase I.

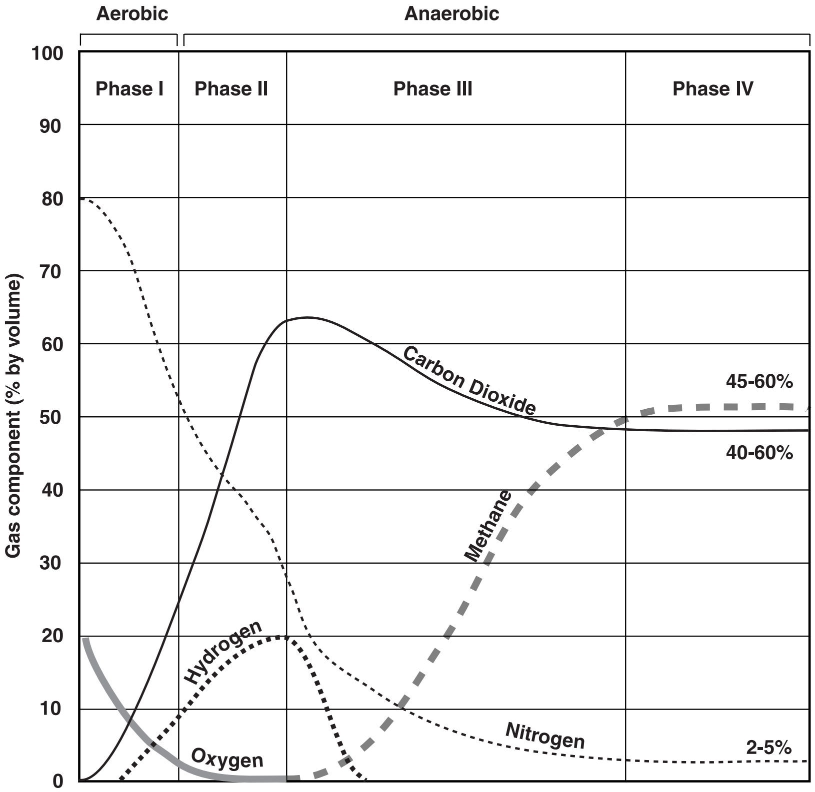
Phase III

Phase III decomposition starts when certain kinds of anaerobic bacteria consume the organic acids produced in Phase II and form acetate, an organic acid. This process causes the landfill to become a more neutral environment in which methane-producing bacteria begin to establish themselves. Methane- and acid-producing bacteria have a symbiotic, or mutually beneficial, relationship. Acid-producing bacteria create compounds for the methanogenic bacteria to consume. Methanogenic bacteria consume the carbon dioxide and acetate, too much of which would be toxic to the acid-producing bacteria.

Phase IV

Phase IV decomposition begins when both the composition and production rates of landfill gas remain relatively constant. Phase IV landfill gas usually contains approximately 45% to 60% methane by volume, 40% to 60% carbon dioxide, and 2% to 9% other gases, such as sulfides. Gas is produced at a stable rate in Phase IV, typically for about 20 years; however, gas will continue to be emitted for 50 or more years after the waste is placed in the landfill (Crawford and Smith 1985). Gas production might last longer, for example, if greater amounts of organics are present in the waste, such as at a landfill receiving higher than average amounts of domestic animal waste.

Figure 2-1: Production Phases of Typical Landfill Gas



Note: Phase duration time varies with landfill conditions

Source: EPA 1997

What conditions affect landfill gas production?

The rate and volume of landfill gas produced at a specific site depend on the characteristics of the waste (e.g., composition and age of the refuse) and a number of environmental factors (e.g., the presence of oxygen in the landfill, moisture content, and temperature).

- ***Waste composition.*** The more organic waste present in a landfill, the more landfill gas (e.g., carbon dioxide, methane, nitrogen, and hydrogen sulfide) is produced by the bacteria during decomposition. The more chemicals disposed of in the landfill, the more likely NMOCs and other gases will be produced either through volatilization or chemical reactions.
- ***Age of refuse.*** Generally, more recently buried waste (i.e., waste buried less than 10 years) produces more landfill gas through bacterial decomposition, volatilization, and chemical reactions than does older waste (buried more than 10 years). Peak gas production usually occurs from 5 to 7 years after the waste is buried.
- ***Presence of oxygen in the landfill.*** Methane will be produced only when oxygen is no longer present in the landfill.
- ***Moisture content.*** The presence of moisture (unsaturated conditions) in a landfill increases gas production because it encourages bacterial decomposition. Moisture may also promote chemical reactions that produce gases.

- ***Temperature.*** As the landfill's temperature rises, bacterial activity increases, resulting in increased gas production. Increased temperature may also increase rates of volatilization and chemical reactions.

The box on the following page provides more detailed information about how these variables affect the rate and volume of landfill gas production.

How does landfill gas move?

Once gases are produced under the landfill surface, they generally move away from the landfill. Gases tend to expand and fill the available space, so that they move, or "migrate," through the limited pore spaces within the refuse and soils covering of the landfill. The natural tendency of landfill gases that are lighter than air, such as methane, is to move upward, usually through the landfill surface. Upward movement of landfill gas can be inhibited by densely compacted waste or landfill cover material (e.g., by daily soil cover and caps). When upward movement is inhibited, the gas tends to migrate horizontally to other areas within the landfill or to areas outside the landfill, where it can resume its upward path. Basically, the gases follow the path of least resistance. Some gases, such as carbon dioxide, are denser than air and will collect in subsurface areas, such as utility corridors. Three main factors influence the migration of landfill gases: diffusion (concentration), pressure, and permeability.

- ***Diffusion (concentration).*** Diffusion describes a gas's natural tendency to reach a uniform concentration in a given space, whether it is a room or the earth's atmosphere. Gases in a landfill move from areas of high gas concentrations to areas with lower gas concentrations. Because gas concentrations are generally higher in the landfill than in the surrounding areas, landfill gases diffuse out of the landfill to the surrounding areas with lower gas concentrations.
- ***Pressure.*** Gases accumulating in a landfill create areas of high pressure in which gas movement is restricted by compacted refuse or soil covers and areas of low pressure in which gas movement is unrestricted. The variation in pressure throughout the landfill results in gases moving from areas of high pressure to areas of low pressure. Movement of gases from areas of high pressure to areas of lower pressure is known as *convection*. As more gases are generated, the pressure in the landfill increases, usually causing subsurface pressures in the landfill to be higher than either the atmospheric pressure or indoor air pressure. When pressure in the landfill is higher, gases tend to move to ambient or indoor air.
- ***Permeability.*** Gases will also migrate according to where the pathways of least resistance occur. Permeability is a measure of how well gases and liquids flow through connected spaces or pores in refuse and soils. Dry, sandy soils are highly permeable (many connected pore spaces), while moist clay tends to be much less permeable (fewer connected pore spaces). Gases tend to move through areas of high permeability (e.g., areas of sand or gravel) rather than through areas of low permeability (e.g., areas of clay or silt). Landfill covers are often made of low-permeability soils, such as clay. Gases in a covered landfill, therefore, may be more likely to move horizontally than vertically.

Factors Affecting Landfill Gas Production

Waste Composition. The more organic waste present in a landfill, the more landfill gas is produced by bacterial decomposition. Some types of organic waste contain nutrients, such as sodium, potassium, calcium, and magnesium, that help bacteria thrive. When these nutrients are present, landfill gas production increases. Alternatively, some wastes contain compounds that harm bacteria, causing less gas to be produced. For example, methane-producing bacteria can be inhibited when waste has high salt concentrations.

Oxygen in the Landfill. Only when oxygen is used up will bacteria begin to produce methane. The more oxygen present in a landfill, the longer aerobic bacteria can decompose waste in Phase I. If waste is loosely buried or frequently disturbed, more oxygen is available, so that oxygen-dependent bacteria live longer and produce carbon dioxide and water for longer periods. If the waste is highly compacted, however, methane production will begin earlier as the aerobic bacteria are replaced by methane-producing anaerobic bacteria in Phase III. Methane gas starts to be produced by the anaerobic bacteria only when the oxygen in the landfill is used up by the aerobic bacteria; therefore, any oxygen remaining in the landfill will slow methane production. Barometric highs will tend to introduce atmospheric oxygen into surface soils in shallow portions of a landfill, possibly altering bacterial activity. In this scenario, waste in Phase IV, for example, might briefly revert to Phase I until all the oxygen is used up again.

Moisture Content. The presence of a certain amount of water in a landfill increases gas production because moisture encourages bacterial growth and transports nutrients and bacteria to all areas within a landfill. A moisture content of 40% or higher, based on wet weight of waste, promotes maximum gas production (e.g., in a capped landfill). Waste compaction slows gas production because it increases the density of the landfill contents, decreasing the rate at which water can infiltrate the waste. The rate of gas production is higher if heavy rainfall and/or permeable landfill covers introduce additional water into a landfill.

Temperature. Warm temperatures increase bacterial activity, which in turn increases the rate of landfill gas production. Colder temperatures inhibit bacterial activity. Typically, bacterial activity drops off dramatically below 50° Fahrenheit (F). Weather changes have a far greater effect on gas production in shallow landfills. This is because the bacteria are not as insulated against temperature changes as compared to deep landfills where a thick layer of soil covers the waste. A capped landfill usually maintains a stable temperature, maximizing gas production. Bacterial activity releases heat, stabilizing the temperature of a landfill between 77° F and 113° F, although temperatures up to 158° F have been noted. Temperature increases also promote volatilization and chemical reactions. As a general rule, emissions of NMOCs double with every 18° F increase in temperature.

Age of Refuse. More recently buried waste will produce more gas than older waste. Landfills usually produce appreciable amounts of gas within 1 to 3 years. Peak gas production usually occurs 5 to 7 years after wastes are dumped. Almost all gas is produced within 20 years after waste is dumped; however, small quantities of gas may continue to be emitted from a landfill for 50 or more years. A low-methane yield scenario, however, estimates that slowly decomposing waste will produce methane after 5 years and continue emitting gas over a 40-year period. Different portions of the landfill might be in different phases of the decomposition process at the same time, depending on when the waste was originally placed in each area. The amount of organic material in the waste is an important factor in how long gas production lasts.

Sources: Crawford and Smith 1985; DOE 1995; EPA 1993.

What conditions affect landfill gas migration?

The direction, speed, and distance of landfill gas migration depend on a number of factors, described below.

- ***Landfill cover type.*** If the landfill cover consists of relatively permeable material, such as gravel or sand, then gas will likely migrate up through the landfill cover. If the landfill cover consists of silts and clays, it is not very permeable; gas will then tend to migrate horizontally underground. If one area of the landfill is more permeable than the rest, gas will migrate through that area.
- ***Natural and man-made pathways.*** Drains, trenches, and buried utility corridors (such as tunnels and pipelines) can act as conduits for gas movement. The natural geology often provides underground pathways, such as fractured rock, porous soil, and buried stream channels, where the gas can migrate.
- ***Wind speed and direction.*** Landfill gas naturally vented into the air at the landfill surface is carried by the wind. The wind dilutes the gas with fresh air as it moves it to areas beyond the landfill. Wind speed and direction determine the gas's concentration in the air, which can vary greatly from day to day, even hour by hour. In the early morning, for example, winds tend to be gentle and provide the least dilution and dispersion of the gas to other areas.
- ***Moisture.*** Wet surface soil conditions may prevent landfill gas from migrating through the top of the landfill into the air above. Rain and moisture may also seep into the pore spaces in the landfill and "push out" gases in these spaces.
- ***Groundwater levels.*** Gas movement is influenced by variations in the groundwater table. If the water table is rising into an area, it will force the landfill gas upward.
- ***Temperature.*** Increases in temperature stimulate gas particle movement, tending also to increase gas diffusion, so that landfill gas might spread more quickly in warmer conditions. Although the landfill itself generally maintains a stable temperature, freezing and thawing cycles can cause the soil's surface to crack, causing landfill gas to migrate upward or horizontally. Frozen soil over the landfill may provide a physical barrier to upward landfill gas migration, causing the gas to migrate further from the landfill horizontally through soil.
- ***Barometric and soil gas pressure.*** The difference between the soil gas pressure and barometric pressure allows gas to move either vertically or laterally, depending on whether the barometric pressure is higher or lower than the soil gas pressure. When barometric pressure is falling, landfill gas will tend to migrate out of the landfill into surrounding areas. As barometric pressure rises, gas may be retained in the landfill temporarily as new pressure balances are established.

How far can landfill gas travel?

It is difficult to predict the distance that landfill gas will travel because so many factors affect its ability to migrate underground; however, travel distances greater than 1,500 feet have been observed. Computer models that use data about the landfill and surrounding soil conditions can predict the approximate migration patterns from existing landfills. More information about models available for assessing landfill gas is provided in Chapter Four.

> A study conducted by the New York State Department of Health found that of 38 landfills, gas migrated underground up to 1,000 feet at 1 landfill, 500 feet at 4 landfills, and only 250 feet from the landfill boundary at 33 landfills.
>
> —(ATSDR 1998)

How does landfill gas enter buildings and homes?

Gases migrating from a landfill may eventually reach buildings and homes. Foundation cracks and gaps, pressure differences between the inside and outside of the building or home, mechanical ventilation systems, and leakage areas (e.g., utility entry points, construction joints, or floor drain systems) provides entry points for gases. Buildings and houses with basements generally provide the most easy access for gases migrating in the soil. The amount of gases let into a building or home depends on a number of factors, including the construction and maintenance practices. The gas concentration in indoor air also depends on the building or home design, the rate of air exchange, and the distance of the building or home from the landfill. Chapter Three provides more information about how people are exposed to gases once the gases have entered buildings or homes.

What types of landfills might be found in communities?

Your community may have different types of landfills within it or nearby:

- ***Municipal solid waste (MSW) landfills*** are used to dispose of household wastes and nonhazardous commercial and industrial wastes. More than 6,000 MSW landfills exist across the United States, although fewer than 3,000 of these are currently active and accepting waste. Landfills constructed after 1979 are required, under Subtitle D of the Resource Conservation and Recovery Act (RCRA), to be designed and operated to prevent contaminant migration to the environment. This design may include liners or collection systems. Landfills constructed before 1979 may not have such environmental safeguards.
- ***Open dumps*** are waste disposal areas that were used before 1979 and constructed without any engineering design and siting criteria, and few, if any, regulatory controls. Open dumps do not meet the RCRA Subtitle D regulations. Open dumps may have accepted household wastes, similar to MSW landfills, as well as commercial and industrial wastes. These dumps did not have liners and rarely used daily cover for sanitary wastes. No precautions were taken to prevent contaminant migration to the environment. Most open dumps were discontinued and covered in the 1960s. Unfortunately, the locations of many of these old dumps are not marked on local planning maps. Some of the current operating MSW landfills began in the 1960s as open dumps or are located adjacent to closed dumps.

- ***Construction and demolition (C&D) waste landfills*** are used for the disposal of construction and demolition waste such as wood, sheet rock, gypsum board, concrete, bricks, and paving materials. As with MSW landfills, C& D waste landfills containing nonhazardous materials are regulated under Subtitle D of RCRA.
- ***Hazardous waste landfills*** are used to dispose of wastes characterized under RCRA as "hazardous." These wastes include solvents, industrial wastes, and construction wastes such as asbestos. Operating or recently closed landfills containing hazardous materials are regulated under Subtitle C of RCRA.
- ***Vegetation waste disposal areas,*** also known as "yard waste and stump fill areas," are used to dispose of vegetation wastes. In many states, these disposal areas were unregulated prior to the 1980s. In areas where burning was prohibited, these areas were used by land developers to bury trees and brush cleared from land used for subdivisions and commercial developments.
- ***Animal waste landfills*** are areas where massive amounts of manure and, possibly, animal carcasses are disposed. There are no specific federal regulations for animal waste landfills. State regulations vary among the states that do regulate the animal waste landfills. As a result of the high organic content, methane production can be significant. Decaying manure and carcasses will produce strong odors. Fires have occurred on some animal waste landfills, increasing health and safety concerns of nearby residents.

This publication focuses primarily on MSW landfills. Of all the types of landfills, MSW landfills are the most significant source of landfill gas emissions, because approximately 60% of the waste in a typical MSW landfill is organic. The Web site of EPA's Office of Solid Waste (**http://www.epa.gov/epaoswer/non-hw/muncpl/facts.htm**) is a good source of basic information about MSW landfills. The Solid Waste Association of North America's (SWANA's) Landfill Gas Operation and Maintenance Manual of Practice is another source of general information about landfills; it can be accessed by a search of the U.S. Department of Energy's (DOE) Information Bridge at the Web site **http://www.osti.gov** or by placing an order for a hardcopy from SWANA's Web site at **http://www.swana.org**.

Are landfill gas emissions regulated?

Prior to 1979, landfills were often merely open dumps with few or no controls to prevent contaminant migration to the environment. Open dumps posed significant environmental and public health hazards. They attracted flies and vermin, and fires that could burn for days often broke out. These dumps had no gas collection systems, nor did they have liners to protect groundwater. All types of waste, including hazardous wastes, could be deposited in landfills before 1979. Some of these dumps have been listed as "Superfund" sites and are now being remediated or are on a waiting list to be remediated. No longer legal, open dumps have been closed or converted into MSW landfills. Past dumps with no gas control systems are the landfill sites most likely to have gas emission concerns.

Many state and local governments have regulated landfills since the middle of the twentieth century; however, before 1979, regulation and enforcement varied widely from site to site. In 1979, the federal government began regulating the siting, construction, operation, and closure requirements for landfills under RCRA. Subtitle D of RCRA addresses MSW and nonhazardous landfills and includes requirements for methane monitoring at the landfill perimeter. Subtitle C of

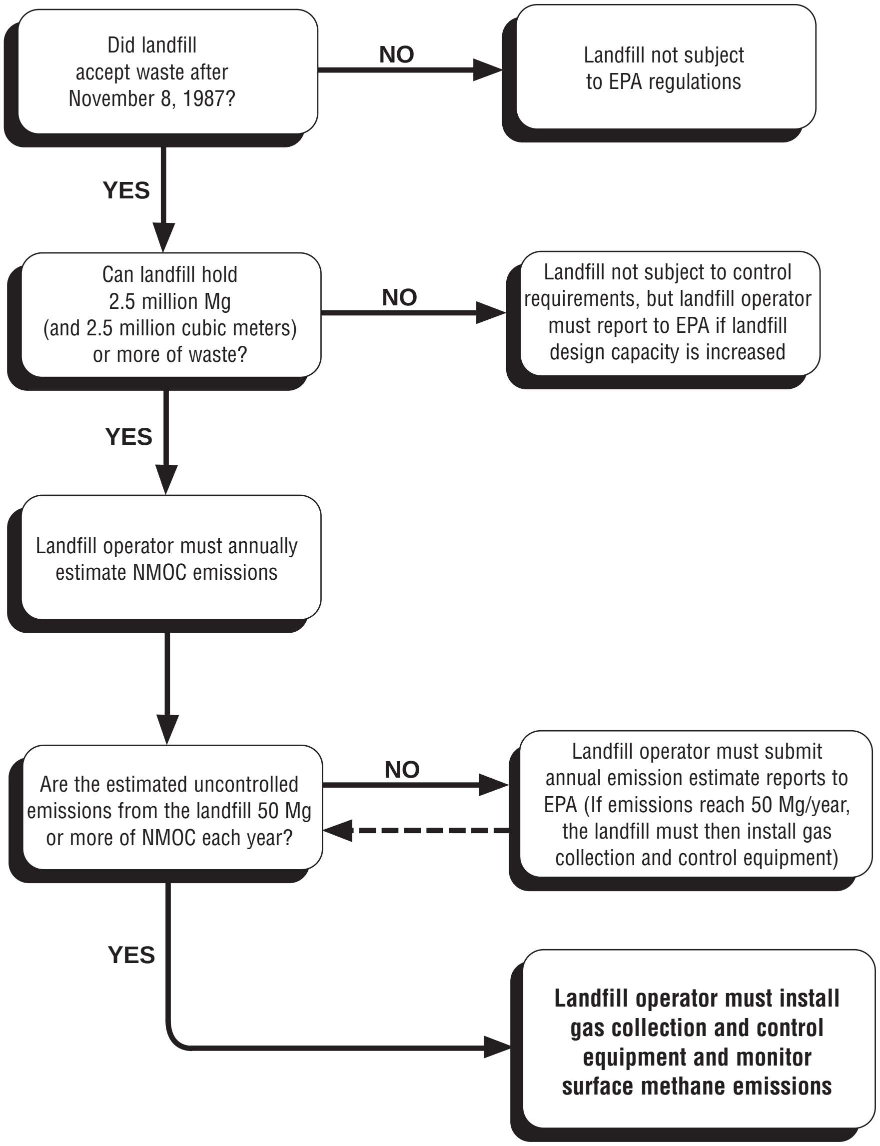
RCRA addresses concerns associated with hazardous waste landfills. In 1996, EPA finalized regulations under the Clean Air Act (CAA)—the New Source Performance Standards and Emissions Guidelines (NSPS/EG)—that address methane and NMOC emissions from MSW landfills. These regulations are described in more detail below, according to the type of waste received by the landfill.

- ***Municipal solid wastes.*** Subtitle D of RCRA regulates the siting, design, construction, operation, monitoring, and closure of MSW landfills. RCRA establishes standards that MSW landfills must meet. These standards are enforced by the state solid waste authority. States may also develop additional standards that are more stringent than RCRA. RCRA requires that owners and operators of MSW landfills ensure that the concentration of methane gas generated by the facility does not exceed 25% of the lower explosive limit (LEL), the lowest percent by volume of an explosive gas in the air that will allow an explosion, for methane in facility structures and that the concentration of methane gas does not exceed the LEL for methane at the facility property boundary. If methane concentrations exceed the LEL at the property boundary, then RCRA requires the landfill owners/operators to notify the proper state authority and develop and implement a plan to correct the problem (see Chapter Three for more information about LELs). The state solid waste authority will determine whether the landfill has properly addressed the problem.

  In 1996, EPA promulgated regulations under the CAA—NSPS/EG—that also address emissions from MSW landfills. These regulations apply to MSW landfills that accepted waste after November 8, 1987. The NSPS/EG require landfills that can hold 2.5 million megagrams (Mg) or more of waste and annually emit 50 Mg or more of NMOCs to install landfill gas collection systems and control landfill gas emissions. The collection systems must meet specific engineering design criteria. Control devices (usually a flare or some other combustion device) must reduce the NMOC emissions from the collected landfill gas by 98% or to a concentration of 20 ppm by volume. Those MSW landfills that are required to install controls based on their NMOC emission rate must also monitor surface methane emissions. If methane emissions are found at concentrations exceeding background levels by more than 500 parts per million (ppm) between 2 and 4 inches from the ground surface, the gas collection system must be adjusted or improved to achieve the 500 ppm level. The NSPS/EG also contain various other testing, monitoring, and reporting requirements that landfills must meet. Figure 2-2 can help determine to what extent, if any, the MSW landfill(s) in the area must comply with the requirements of the NSPS/EG. The NSPS/EG can be found in the Code of Federal Regulations (CFR), at 40 CFR Part 60, Subparts Cc and WWW. Additional information can be found at **http://www.epa.gov/ttn/uatw/landfill/landflpg.html**.

- ***Construction and demolition wastes.*** Most C&D waste is classified as nonhazardous and can be disposed of in an MSW landfill or in a C&D landfill (a landfill that accepts only C&D waste). The siting, design, construction, operation, monitoring, and closure of landfills containing nonhazardous C&D wastes are regulated under Subtitle D of RCRA. Air emissions from C&D landfills are not regulated and are not generally a concern, because C&D wastes do not contain much organic matter (which is necessary to produce landfill gas). However, if gypsum wallboard is present in C&D waste, hydrogen sulfide may be produced, particularly if moisture is introduced into the waste. Because of

Figure 2-2: How to Determine if a Landfill Must Comply with NSPS/EG[a]



[a] The New Source Performance Standards (NSPS) is a federal rule that applies to landfills that started construction or increased their total design capacity after May 30, 1991. The Emission Guidelines (EG) apply to older landfills and are implemented and enforced through state plans (or a federal plan in cases where states have not developed plans). The landfill gas control requirements are the same.

hydrogen sulfide's objectionable rotten-egg odor, C&D landfills that emit hydrogen sulfide often find themselves facing numerous complaints from the surrounding communities. Operators of these landfills often find that they must install gas control systems to reduce odors caused by the hydrogen sulfide gas.

Some C&D wastes may be classified as hazardous wastes because they contain hazardous materials, such as asbestos. Hazardous C&D waste must be disposed of in a hazardous waste landfill, as described below.

- ***Hazardous wastes.*** The siting, design, construction, operation, monitoring, and closure of landfills containing hazardous wastes are regulated under Subtitle C of RCRA. Hazardous waste landfills are strictly regulated because they handle wastes that pose a greater risk to the public than nonhazardous household waste. Air emissions from hazardous waste landfills are not specifically regulated under RCRA Subtitle C. However, Subtitle C does address air emissions from the generation, storage, treatment, and transport of hazardous wastes.

For more information about how U.S. landfills are regulated, visit the Web site of EPA's Office of Solid Waste at **http://www.epa.gov/epaoswer/osw/index.htm**.

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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?

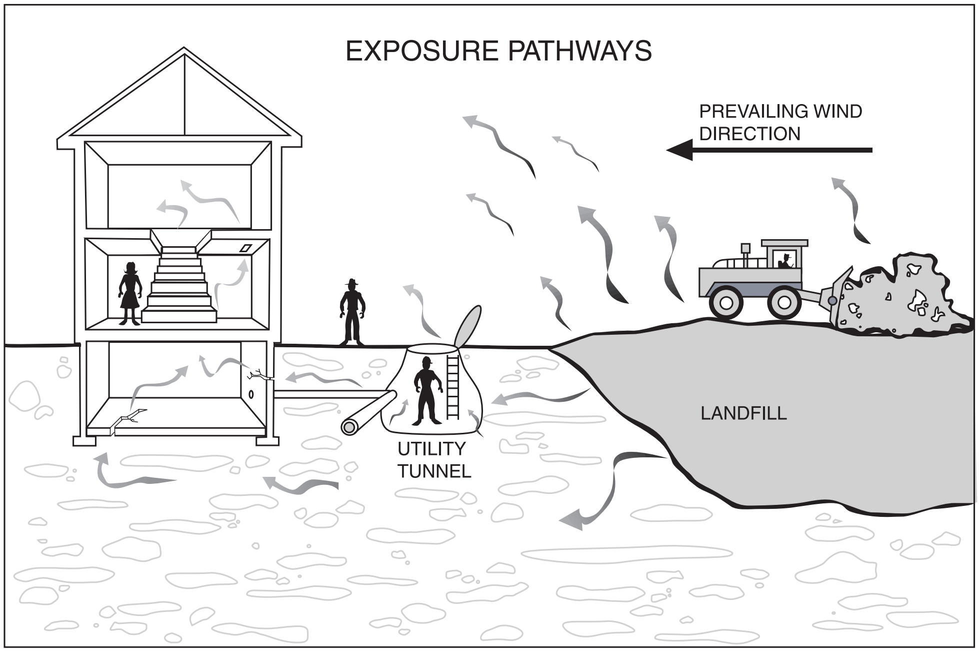
People may be exposed to landfill gases either at the landfill or in their communities. As discussed in Chapter Two, landfill gases may migrate from the landfill either above or below ground. Gases can move through the landfill surface to the ambient air. Once in the air, the landfill gases can be carried 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.

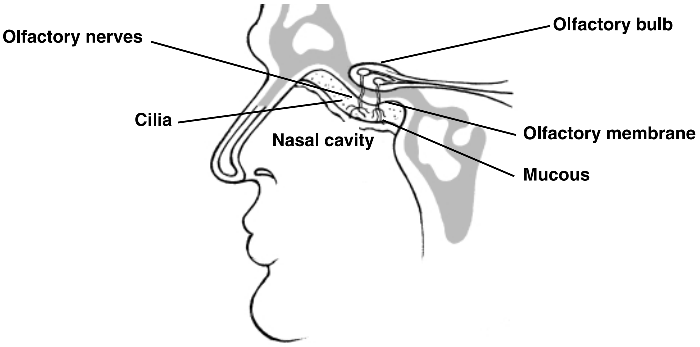
  Humans are extremely sensitive to hydrogen sulfide odors and can smell such odors at concentrations as low as 0.5 to 1 part per billion (ppb). At levels approaching 50 ppb, people can find the odor offensive. Average concentrations in ambient air range from 0.11 to 0.33 ppb (ATSDR 1999a). According to 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



- ***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.

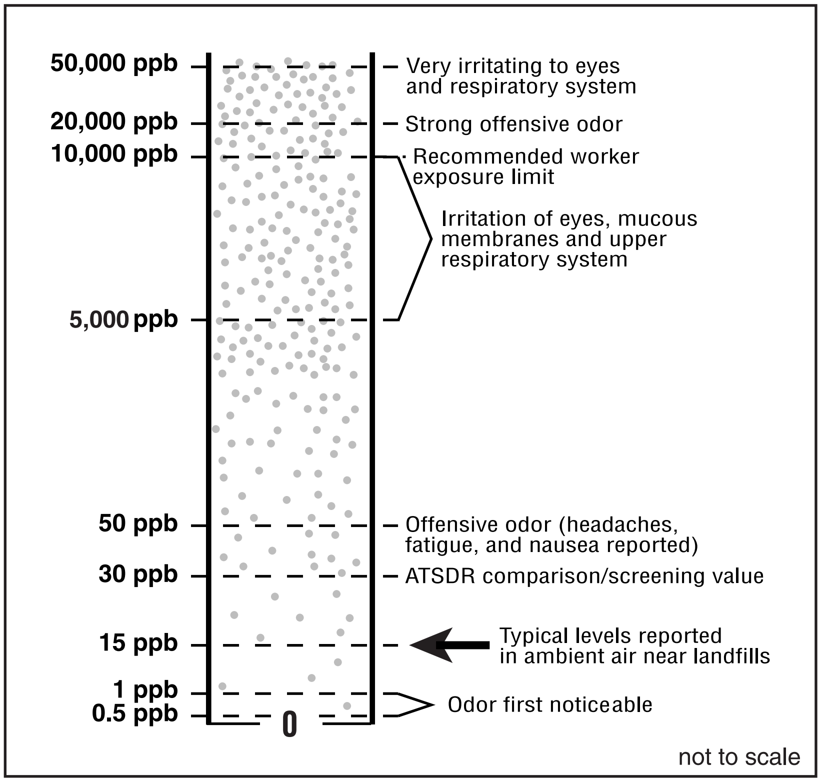
Experimental animal studies have generally found that hydrogen sulfide does not cause harm at levels as high as 5,000 ppb. Studies of pregnant mice with daily exposures of up to 20,000 ppb concluded that hydrogen sulfide does not alter fetal development. One study showed no effects at levels up to 150,000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

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[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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CHAPTER

4 Monitoring of Landfill Gas

Environmental health professionals are rarely required to design and implement sampling and monitoring plans at landfills, but you might be asked to review and comment on such plans. In addition, you might need to review and interpret sampling and monitoring data, when available, to evaluate potential public health hazards. To make such tasks easier, this chapter provides basic information (e.g., monitoring program design, sampling and monitoring equipment, and data interpretation) about the different types of landfill gas sampling methods that you are most likely to encounter.

It is important to remember that monitoring data taken at landfills do not necessarily reflect the levels of contamination to which people may be exposed. However, these data usually offer some insight into either general air quality, landfill gas migration, or possible health hazards. In general, monitoring of gases that emanate from landfills falls into the following five categories:

- Soil gas monitoring
- Near surface gas monitoring
- Emissions monitoring
- Ambient air monitoring
- Indoor air monitoring

Table 4-1 presents a brief overview of the key features of each type of monitoring.

Data collected from these different monitoring activities have considerably different public health implications. Following an overview of landfill gas sampling approaches, this chapter reviews the five types of monitoring activities separately. In addition, mathematical modeling can be used to help answer questions about landfill emissions data. This chapter presents a brief summary of factors to consider when reviewing air modeling results.

Landfill Gas Sampling Approaches: An Overview

Many different types of landfill gas sampling approaches exist—too many to review in this manual. However, two important factors in selecting an appropriate landfill gas sampling approach include the sampling location and the sampling methods. The sampling location and sampling methods are selected according to the data uses and questions to be answered by the overall sampling program. Some examples of location, or placement, of gas monitors are described in the box on page 33.

Table 4-1: Key Features of Different Types of Monitoring of Landfill Gases

Type of Monitoring	Description of Monitoring	Typical Parameters Reported	Relevance to Public Health
Soil Gas	Soil gas monitoring programs measure the concentrations of chemicals in the vapor space of soils. Measurements of soil gas levels are taken at depth with the use of probes or wells.	Most landfills are required by federal law to report levels of methane around the landfill perimeter. Oxygen, carbon dioxide, and nitrogen are frequently reported. Sometimes H_2S and other specific NMOCs, such as vinyl chloride, might be reported if federal or state regulators suspect a significant problem. Pressure, in inches of water, is also frequently reported from permanent soil gas probes.	Because soil gas monitoring data at many MSW landfills typically (though not always) characterize levels of only methane, the data are generally useful for evaluating risks of explosion and for getting a qualitative sense of whether landfill gases are migrating in the soils to off-site locations.
Near Surface Gases	Measures the concentrations of gases at a point no higher than 4 inches above the ground surface.	Methane is the most common gas monitored but VOCs and H_2S are sometimes reported.	Outside air methane concentrations do NOT pose an inhalation or explosion hazard. Near surface monitoring of methane on the landfill does not provide useful information to determine impacts on the health of adjacent residents. Monitoring can qualitatively indicate whether high levels of landfill gas are escaping from the landfill surface or whether the landfill gas collection and control system is working well to minimize emissions.
Emissions	Emissions monitoring programs measure the rate at which chemicals are released from a particular source, such as landfill surfaces, flares, or stacks.	Landfill studies have measured emission rates for various pollutants, such as methane and NMOCs, from landfill surfaces and combustion by-products of flares and other treatment units.	Chemical-specific emissions data are useful for identifying potential contaminants of concern at landfills, but they do not characterize the concentrations of chemicals that people actually breathe. Exposure concentrations can be estimated from emissions data, but such estimates can be highly uncertain.
Ambient Air	Ambient air monitoring programs measure levels of pollution in outdoor ambient air, or the air that people breathe.	Ambient air monitoring can be conducted for a wide range of pollutants. Near landfills, air monitoring is most commonly conducted for EPA's criteria pollutants and NMOCs.	Because ambient air monitoring data characterize levels of pollution in the air that people breathe, they usually provide the best measure for air exposure concentrations in the vicinity of landfills. Of course, environmental health professionals still need to critically evaluate ambient air monitoring data to put them into proper perspective.
Indoor Air	Indoor air monitoring programs measure levels of contamination in indoor air spaces.	Indoor air monitoring for methane is required at structures on many landfill properties. Methane monitoring at off-site locations and NMOC monitoring is usually only performed to address site-specific concerns. Oxygen levels in confined spaces, such as buried utilities, are measured to determine if carbon dioxide and/or methane gases have replaced sustainable oxygen.	Indoor air monitoring data are useful for evaluating risks of explosions and exposures to contaminants within homes. Emissions from household products and tasks might confound these measurements, and levels measured in one home generally are not representative of levels in other homes, even nearby residences.

Location of Landfill Gas Monitors

Landfill gas monitors are typically placed in three types of locations at or near landfills; these are subsurface, surface, or enclosed space. The three types of monitoring locations address different landfill gas concerns and can be used either alone or together in a sampling program. Note that these systems generally do not measure landfill gas levels at points of human exposure.

Subsurface Systems—Subsurface systems measure concentrations of contaminants in the soil gas at locations beneath the soil-air interface. The depth of sampling can range from a few inches to many feet below the surface.

Surface Systems—Surface systems measure concentrations of gas within a couple of inches above the soil-air interface.

Enclosed Space Systems—Enclosed space systems monitor gases in indoor air or confined areas overlying or adjacent to landfills, such as buildings, subsurface vaults, utilities, or any other spaces where the potential for gas buildup is of concern.

In addition to the sampling location, several methods of landfill gas collection can be used in a landfill gas sampling approach. Examples of these methods, and their implications, follow:

- ***Portable vs. stationary sampling equipment.*** Some gas sampling can be performed with *portable monitors*, which typically are hand-held instruments that can be easily carried around a landfill. This type of device is useful for conducting an initial screening of landfill gas migration pathways or for identifying the source of methane leaks. Stationary monitors, on the other hand, usually are installed at fixed locations, where they remain for the duration of the intended monitoring. *Stationary monitors* are typically, though not always, capable of generating higher quality data than portable monitors.
- ***Grab sampling vs. continuous monitoring.*** This distinction applies to most types of landfill gas monitoring (e.g., soil gas, emissions, ambient air, and indoor air). By definition, *grab sampling* is a one-time measurement of gas concentrations, thus providing a "snapshot" of landfill gas composition at a given place and time. This type of sampling is generally not useful for evaluating changes in landfill gas composition over the long term, unless it is conducted at regular intervals according to a detailed plan. In contrast, *continuous monitoring* devices constantly sample and analyze gas concentrations. Some are capable of documenting fluctuations in concentrations over short intervals, while others can measure only average concentrations. All continuous monitors, however, provide insight into changes in gas composition over the long term.
- ***Analysis of samples in the laboratory vs. analysis in the field.*** Depending on the data needs, gas samples are usually either collected and sent to a laboratory for analysis or analyzed directly in the field. *Laboratory analysis* may take days or weeks to perform and can be expensive, but this approach generates highly accurate and precise results and can measure concentrations of many different pollutants. Alternatively, *real-time monitoring* (or analysis in the field) reports concentrations as soon as they are measured; in some cases, these devices can measure changes in concentration from minute to minute. Most real-time monitors, however, measure concentrations of only one pollutant and are not as sensitive as laboratory analysis.

The features of a particular landfill gas sampling program vary from landfill to landfill, and the ideal sampling strategy for one landfill may not be appropriate for the next. For most landfills, regulatory requirements dictate the features selected for gas sampling (e.g., EPA's soil gas monitoring requirements are a major consideration for the sampling conducted at most MSW landfills).

Soil Gas Monitoring

This section defines soil gas monitoring and how it relates to landfills, discusses why soil gas is often monitored at landfills, and presents information environmental health professionals should consider when reviewing soil gas monitoring data.

What is soil gas monitoring?

As Chapter Two describes, decomposing waste in landfills generates gases containing many chemicals that transport through soils and may eventually be released to the surface. While in the soils, the landfill gas is typically referred to as "soil gas." Soil gas monitoring, therefore, is the measurement of concentrations of gases in the subsurface.

Why is soil gas monitored at landfills?

There are many reasons for monitoring levels of contaminants in soil gas at or near landfills. The three main reasons that such monitoring is performed are reviewed below, though soil gas monitoring might be conducted for other reasons. Information about sampling methods and the relevance of the monitoring results to public health is presented later in this chapter.

- ***To meet regulatory requirements.*** According to EPA regulations under RCRA (Subtitle D), MSW landfills must conduct soil gas monitoring for methane. Depending on the date of construction, some MSW landfills may be exempt from these RCRA regulations. EPA regulations provide flexibility for how states and Indian tribes implement these regulations. As a result, landfills operating in some states or tribal areas might be subject to different regulations than landfills operating in other areas. The data collected in fulfillment of these regulations serve two important purposes: they provide environmental regulators with information about the performance of landfill gas collection systems, and they characterize the extent to which accumulation and migration of landfill gas might pose an explosion hazard.

  As discussed in Chapter Two, under Subtitle D of RCRA, MSW landfills must monitor methane around the landfill perimeter. If methane concentrations at the monitoring stations at the property boundary exceed the LEL, the lowest percent by volume of an explosive gas in the air that will allow an explosion, then RCRA requires the landfill to report the exceedance to the proper state authority and develop and implement a plan to correct the problem (see Chapter Three for more information about the LEL of landfill gas). The state solid waste authority will determine whether the landfill has properly addressed the problem. The methane monitoring must be performed not only while landfills are active, but after they close.

- ***To characterize off-site fire or explosion hazards.*** At some landfills, soil gas monitoring for methane is performed at off-site locations to address concerns of landfill gas migration and potential explosion hazards.

- ***To quantify off-site migration of chemicals.*** At some landfills, the landfill has been identified as a hazardous waste site under federal or state environmental regulations or residents are concerned about the trace amounts of chemicals (mostly NMOCs) that might migrate with the soil gas to residential areas. Migration of chemicals from these landfills cannot be directly addressed by methane monitoring data. Therefore, environmental agencies, or the residents themselves, might organize sampling efforts as part of site investigation efforts to identify the many contaminants in soil gases as well as their soil gas concentrations. Such chemical-specific soil gas monitoring provides the most detailed information about levels of contamination in landfill gas.

How are soil gas samples collected?

Soil gas samples are collected from temporary monitoring probes (often labeled *punch probes* or *punchbars*), permanent soil gas monitoring wells, and landfill gas collection wells and vents. Soil gas sample locations and sampling methods vary from landfill to landfill, depending on monitoring concerns or regulatory requirements.

What do soil gas monitoring data tell you?

Soil gas monitoring results may provide a great deal of information about landfill gases and how they are moving through the landfill. Soil gas monitoring can characterize methane and other gases, such as NMOCs, in concentrations within the landfill and around its perimeter. Important factors to consider when interpreting results include the sample location, frequency, and data quality. Based on the location of soil gas monitoring wells or probes, data can identify off-site subsurface pathways and on-site or off-site buildings that may be endangered by migrating methane and other gases. This information may be used by decision makers to determine if and what soil gas collection and treatment is needed to protect public safety and health.

However, soil gas monitoring data do not provide actual measurements of the gases and their concentrations that people living near a landfill may inhale. Soil gas samples are collected beneath the landfill surface, and gas concentrations will change as the gases move horizontally in the subsurface or vertically into the ambient air. In addition, environmental regulations may require only methane monitoring. Other gases, such as NMOCs, may be present in the subsurface. When reviewing soil gas data, environmental health professionals should be careful to consider the sampling locations in relation to potentially exposed populations and sample analyses conducted in relation to the gases, especially NMOCs, that may be present.

Some questions to consider in a review of soil gas data to ensure that they are truly representative of subsurface conditions are listed on pages 36 and 37. Understanding the pressure and water level during sampling provides additional information about the sampling results. Pressure is important because it is key factor influencing landfill gas movement. As discussed in Chapter Two, gases move from areas of high pressure to areas of low pressure. Therefore, if the atmospheric pressure is higher than the pressure in the landfill, ambient air will enter the soil gas well/probe. Any samples taken under these conditions would not be representative of the landfill gas. Water level is important because water can be a barrier to gas movement. When a soil gas well/probe is filled with water, gases are restricted from moving into the well/probe. Samples collected from a water-filled well/probe would not be representative of the landfill gas. Appendix D provides a case example of a landfill at Wright-Patterson Air Force Base in Ohio where the filling of soil gas wells/probes with water was a problem.

Questions To Consider When Reviewing Soil Gas Monitoring Data From Landfills

Gases Selected for Monitoring

- What gases are routinely monitored?
- Do these include the chemicals of concern identified by the community, regulators, and public health officials?
- Do routine reports include oxygen and carbon dioxide when methane levels are reported?
- Do the chemicals selected for monitoring include those expected to be present in the greatest quantities and/or those that are the most toxic?
- Are there any data gaps in the chemicals selected for monitoring?

Pressure Monitoring

- Are atmospheric (barometric) and well/probe pressures included in routine reports?
- Do any of the soil gas wells/probes have dedicated pressure gauges?

Sampling Methods

- Were EPA-approved sampling methods selected? If not, why?
- Are the sampling methods the same or comparable to methods recommended by the Solid Waste Association of North America and/or state regulatory programs such as the one operated by the Missouri Department of Natural Resources (see Appendix E)?
- Are the selected methods recommended for measuring the chemicals selected for monitoring?
- Are water levels within the soil gas well/probe measured after taking the gas samples?

Sampling Equipment

- Was the sampling equipment designed to operate under the conditions in which it was used?
- Were the manufacturer's limitations on the environments in which the equipment would give accurate readings followed?

Monitor Well Construction and Depth of Screened Intervals

- How far below land surface is the bottom of the boreholes for wells and probes?
- How far below land surface does the well/probe screen begin and end (top and bottom of screen interval)?
- How does the well/probe depth and screen interval compare to the top and bottom of buried waste and the top of the groundwater surface (water table)?
- Does the routine or periodic monitoring indicate if the well/probe is dry or partially filled with water?

- Is there a geologic report associated with the well construction report?
- Has there been a geologic analysis to predict and investigate possible subsurface pathways?

Monitoring Locations

- Is there a perimeter monitoring program with adequate spacing between permanent soil gas monitoring wells?
- Are there monitoring wells adjacent to on-site buildings?
- Are there monitoring wells between landfill boundaries and adjacent properties with occupied buildings?
- Are there passive vents on the landfill that are routinely monitored?
- Has a surface sweep survey with handheld instruments been performed to locate “hot spots” at the surface of the landfill that may be the best location for permanent monitoring wells/probes?

Other Sources

- Are there other possible sources of contaminated soil gases such as underground storage tanks, spilled petroleum products, or leaking natural gas pipes?

Monitoring Schedules

- How often are the monitoring wells/probes sampled (daily, weekly, monthly, quarterly)?
- Are wells adjacent to occupied buildings on the landfill sampled at least monthly?
- How often is sampling performed on gas collection and venting systems?
- If significant levels of NMOCs have been historically reported, has monitoring continued frequently enough to determine historical trends of high and low concentration areas across the landfill or at property boundaries?
- Does the monitoring schedule include provisions for sampling during worst-case climatic periods (e.g., when the surface of the landfill is frozen or saturated)?

Data Quality Parameters

- What percent of attempted sampling events were successful?
- How accurate were the reported sampling results?
- How precise were the reported sampling results?
- Do oxygen levels in samples approach atmospheric levels, indicating a leaking well casing or faulty sampling equipment?
- What percent of the monitoring wells/probes are either saturated with water or do not provide a consistent methane reading?
- Is there regulatory oversight of sampling team performance?

Where can I get more information about soil gas monitoring?

General information about soil gas sampling can be found in the resources listed below. In addition, state and federal environmental officials are an excellent resource for site-specific insights.

- The Subtitle D RCRA regulations for MSW landfills can be found in 40 CFR Part 258, which can be viewed through EPA's Office of Solid Waste Web site at **http://www.epa.gov/epaoswer/osw/laws-reg.htm**.
- EPA maintains a Web site with general information about emissions sampling methodologies, and some of this information is specific to measuring soil gas at landfills. The site is **http://www.epa.gov/ttn/emc**.
- EPA Office of Emergency and Remedial Response is testing new technical guidance for evaluating landfill gas emissions at Superfund sites in 2001. The proposed guidance should be issued in 2002. For latest information on the existing and new guidance for Superfund sites check the EPA Web site **http://www.epa.gov/superfund/index.htm**.
- The Missouri Department of Natural Resources, Solid Waste Management Program has published several technical bulletins that address soil gas monitoring at landfills. Copies of these technical bulletins are provided in Appendix E, but can also be found at **http://www.dnr.state.mo.us/deq/swmp/publist.htm**. More information on soil gas monitoring for deep soil gas migrations, typically below 10 feet (3 meters) can be found on the Missouri Web site at: **http://www.dnr.state.mo.us/deq/swmp/ fgtask3a.htm** (Task 3a—An Analysis of Landfill Gas Monitoring Well Design & Construction) and **http://www.dnr.state.mo.us/deq/swmp/fgtask3b.htm** (Task 3B—Landfill Gas Sampling Protocol).

Near Surface Gas Monitoring

This section defines near surface gas monitoring and how it relates to landfills. This section also discusses why near surface gases might be monitored at landfills, and presents information that environmental health professionals should consider when reviewing the resulting data sets.

What is near surface gas monitoring?

Near surface gas monitoring is the measurement (usually by portable instruments) of gas concentrations within a few inches of the surface of the landfill.

Why is near surface monitoring performed at landfills?

Near surface monitoring of landfill gases may be performed to determine the need for, and the design of, a LFG control system. The near surface monitoring is also used to determine if a LFG control system is adequately preventing methane and other landfill gases from escaping in high quantities through the landfill cover. Under the Clean Air Act, large landfills that are required to install landfill gas collection and control systems by the NSPS/EG must perform near surface methane monitoring quarterly to show that the system is operating properly. Corrective action must be taken if methane readings are more than 500 ppm above background. (Other testing and monitoring requirements of the NSPS/EG are described later in this chapter.)

How is near surface gas monitoring performed?

A common method of near surface gas monitoring is the use of a portable instrument such as a organic vapor analyzer-flame ionization detector (OVA/FID). Normally, the instrument is calibrated for methane but it can be calibrated for other gases commonly found in landfills. The OVA may be fitted with a funnel over the monitoring probe inlet. The probe inlet and funnel are then held within 2 to 3 inches of the ground surface and the measurement of gas is recorded by the sampling technician.

Using a method known as landfill gas sweeping or emissions screening, the sampling technician walks over the surface of the landfill in either a random method or over a pre-defined grid. The sampling technician records the instrument readings, making careful note of the geographic location of each measurement and the surface conditions. The measurements may be recorded as parts per million, percent by volume, or percent of lower explosive limit, depending upon the type of portable instrument used.

A grab sample may also be taken using a sampling device fitted with a Tedlar® bag or with a SUMMA®-polished canister. In both cases the samples are taken to a laboratory for analysis. The laboratory analysis may yield results for many more specifically identified constituents of landfill gas than use of portable instruments.

A combination of a portable instrument and Tedlar® bag sample is sometimes used to provide a comprehensive analysis of gases emitted through the landfill cover. The portable instrument is used to locate “hot spots,” places in the landfill surface where relatively high concentrations of methane are detected. A sample is then taken using the Tedlar® bag and sent to a laboratory for qualitative and quantitative analyses of several contaminants composing landfill gas.

Results from near surface gas sampling should always be reviewed in context of meterologic conditions at the time of sampling and with knowledge of the height of the probe inlet from the surface of the landfill. Even moderate surface winds of 5 to 10 mph will greatly dilute the gas sample taken at 4 inches from the surface.

What do near surface gas monitoring data tell you?

Near surface gas data provide the concentrations of gases, usually just methane, that are moving through the cover of the landfill into the atmosphere. If laboratory analysis of samples is used, the results may help characterize the NMOCs being emitted by the landfill into the atmosphere.

Near surface gas data may indicate the location of point sources of relatively high concentrations of landfill gases such as cracks in the landfill cover. Such information may be useful in locating permanent soil gas probes for long term monitoring or gas recovery wells to control the release of landfill gases. Near surface gas monitoring is also useful inside buildings to locate sources of landfill gas movement into the building. Cracks and openings into the buildings may then be sealed to reduce the amount and concentrations of infiltrating gases.

However, near surface gas data do not indicate the concentrations of gases that people may be breathing because of the effects of rapid dilution that is normally expected of gases traveling from the surface of the landfill to the 3- to 5-foot height that may be considered the breathing zone for many people. Furthermore, near surface gas monitoring is normally only performed on the landfill or at the boundary of the landfill. Additional dilution of gases will occur during the travel of contaminants from the landfill to nearby homes and businesses.

Near surface gas data may be used in computer air models that estimate the level of contamination in ambient air in adjacent communities. The quality and validity of such models for public health purposes will greatly depend on the quality and validity of the gas data and site specific meteorologic measurements, as well as the validity of the assumptions and defaults values used in the computer model. Air models and estimates that substitute too many default values for site specific measurements have very limited value for public health conclusions about breathing zone concentrations.

Where can I get more information about near surface gas monitoring?

The CAA regulations (NSPS/EG) for MSW landfills can be found in the Code of Federal Regulations, at 40 CFR Part 60, Subparts Cc and WWW, available on the Internet at **http://www.access.gpo.gov/nara/cfr/waisidx_00/40cfr60_00.html**. The NSPS/EG surface methane monitoring requirements and methods are in section 60.753, 60.755, and Method 21 of Appendix A of Part 60. Additional summary information on the NSPS/EG is available on the EPA Web site at **http://www.epa.gov/ttn/uatw/landfill/landflpg.html**.

The Landfill Gas Operation and Maintenance Manual of Practice published in 1997 by the Solid Waste Association of North America (SWANA) provides detailed explanation of landfill gas monitoring and instrumentation. The published manual can be ordered via the SWANA Web site **http://www.swana.org**. A draft version is available online at the Department of Energy Information Bridge at the Web site **http://www.osti.gov**.

Emissions Monitoring

This section defines emissions monitoring and how it relates to landfills, discusses why emissions might be monitored at landfills, and presents information that environmental health professionals should consider when reviewing emissions monitoring data.

What is emissions monitoring?

Unlike soil gas and near surface gas monitoring, which measure the *concentrations* of chemicals in landfill gas, emissions monitoring measures the *rates* at which chemicals in landfill gases are released from landfills. Emissions sources at landfills that are most frequently monitored are the landfill surface itself and landfill gas combustion units (e.g., flares or other combustion devices).

Why are emissions monitored at landfills?

Landfill gas emissions may be monitored for one or more of the following reasons: to comply with federal and state environmental regulations; to judge the need for, or effectiveness of, a landfill gas control system; and/or to determine the general composition and volume over time of air contamination emanating from the landfill. Emission rate estimates or monitoring may also be used to assess whether it is technically and economically feasible to recover and use the landfill gas for energy production. For example, landfill gas can be collected and combusted in boilers to produce steam to heat a manufacturing process in a building, or it can be combusted in a gas turbine or internal combustion engine to generate electricity.

As mentioned in Chapter Two, to comply with the CAA, large landfills (those that can hold at least 2.5 Mg and 2.5 million cubic meters of waste) that have estimated uncontrolled emission rates of 50 Mg NMOC/year or more must install landfill collection and control systems. To estimate NMOC emissions, the landfill must use a model (described later in this chapter). One input to the model is the NMOC concentration in the landfill gas, which can be measure through sampling and analysis procedures described in the NSPS/EG (sometimes referred to as Tier 2 testing), or a default NMOC concentration provided in the rule can be used. These large landfills must control emissions with (1) a well-designed and well-operated gas collection system and (2) a control device (usually flare or other combustion device) capable of reducing emissions in the collected gas by 98 weight percent. Depending on the type of control device, an initial stack test to measure the NMOC emission rate and percent destruction may be required. To indicate whether the landfill gas collection system is operating properly, landfills must also periodically monitor surface methane concentrations (as described earlier in this chapter in the near surface monitoring section). Temperature and nitrogen or oxygen levels also must be monitored at the landfill gas collection wells.

The small landfills, often owned and operated by local governments, may be exempt from the requirements of the NSPS. EPA estimated that 90% of landfills are exempted from the NSPS regulations. However, the recent trend is toward larger landfills, so in the future a greater percentage of landfills may be subject to the NSPS/EG.

The distinction between emissions monitoring and emissions estimation is reviewed below.

Emissions Estimation vs. Emissions Monitoring

Scientists generally use one of two techniques to quantify air emissions from sources: they either estimate the emissions or measure them. To estimate emissions, scientists perform calculations or use models to predict the rate at which sources may release chemicals to the air. The uncertainty in the assumptions and input values for these calculations make the estimated emission rates uncertain as well. Though some models have been derived from years of research on the transport of chemicals from landfills into the air, models ultimately provide estimates of emissions. Because the accuracy of these estimates cannot be quantified, modeled emission rates should be carefully scrutinized and viewed as somewhat uncertain.

In some cases, scientists will actually measure the air emissions from sources. Measuring emissions from an entire landfill is a challenging task, primarily because landfill emissions can occur over a surface that spans hundreds, or even thousands, of acres. Moreover, there are many different types of emissions sources at a landfill, such as evaporative losses through the landfill surface, mobile source emissions from dump trucks, and stack emissions from landfill gas treatment devices (e.g., flares). Monitoring studies rarely measure the emissions from all possible sources at a landfill. When reviewing emissions monitoring studies from landfills, environmental health professionals should critically evaluate all reported results, because they can be biased by poor study design and other factors.

In a very few cases, a landfill might be identified as a hazardous waste site under federal or state regulations. In these instances, regulatory agencies might require landfill owners to perform limited emissions monitoring to address specific regulatory or enforcement actions, but monitoring for this reason is not common.

Although some landfill emissions are monitored as part of a regulatory process, often air emissions monitoring at landfills, particularly at MSW landfills, is conducted for nonregulatory purposes. These purposes can include addressing community concerns regarding potentially toxic emissions, conducting scientific research on air quality impacts of landfills, or validating the predictions of emissions models. More information about predictive models is provided later in this chapter.

How are emissions measured?

Emissions are measured by the use of various combinations of field sampling techniques and laboratory analytical techniques (when laboratory analysis of samples is necessary). The techniques selected for a given monitoring effort depend on the type of source being evaluated. Some examples of sampling approaches follow:

- When measuring emissions from the surfaces of landfills, field teams have used “flux chambers,” which collect the passive release of landfill gases for later analysis, either on site or in a laboratory to determine the emission rate. (Other monitoring techniques that provide near-surface ambient concentrations rather than emission rates are described previously in this chapter.)
- Surface emissions are also being measured by fourier-transformed infrared-red (FTIR) or ultra-violet spectroscopy (UVS) sampling techniques. FTIR and UVS are spectroscopic sampling techniques that detect and identify contaminants in the air along a straight line (e.g., the boundary of a landfill or across the landfill surface). UVS is typically set up for specific compounds (usually inorganic gases), but FTIR can be used for multiple compounds (usually organic gases). The principle is that the infrared or UV light is generated and then passed to a receptor in a line-of-sight position along a boundary of concern. The receptor either analyzes the spectrography of the light or reflects it to another receptor, which then does the analysis. This second receptor may be part of the source instrument. The spectroanalysis can identify specific compounds and concentrations in the space between the source and the receptor. However, the units are usually given in a concentration of volume per unit distance (e.g., ppm-m), mass per area of the beam (e.g., $\mu g/m^2$), or mass per volume sampled ($\mu g/m^3$) rather than an emission rate
- When measuring emissions from passive vents at landfills, field teams typically collect a sample over a given time frame in some type of enclosed device, such as a Tedlar® bag or a SUMMA®-passivated stainless steel canister.
- When measuring emissions from a stack with a high flow rate (e.g., the effluent from a landfill gas incinerator), field teams typically insert a sampling probe directly into the stack. The probe then draws a known volume of the stack air into another device, such as those mentioned above. Various analytical methods can be used depending on the compounds being measured. For example, total NMOC may be measured at the inlet and outlet of an enclosed combustion device to show compliance with the NSPS/EG. EPA Method 25C is used for this purpose. Specific organic pollutants may also be measured as part of a local health evaluation or for a state air toxics rule. EPA Method 18, measurement of gaseous organic compound emissions by gas chromatography, is a method for measuring individual organic hazardous air pollutants.

  Sometimes, sulfur dioxide (SO_2) and nitric oxides (NO_X), which are products of combustion, are measured initially or are continuously monitored as part of new source permitting requirements or to comply with other federal and state rules that apply to some boilers or other combustion devices. Carbon monoxide (CO) may also be monitored as an indicator of good combustion. There are continuous emission monitors (CEMs) available for SO_2, NO_X, and CO. EPA’s standard sampling and analytical methods for criteria and toxic air pollutants are published in 40 CFR Part 60, Appendix A, and 40 CFR Part 63, Appendix A.

The sampling strategy for a given study ultimately depends on other factors in addition to the type of emissions source. These other factors include cost, access, data quality needs, and chemicals selected for monitoring.

What do emissions monitoring data tell you?

When working on most landfills, chances are you will not encounter emissions monitoring data. When you do, however, it is important to interpret these data in proper context. Though useful for characterizing the relative quantities of chemicals released from a landfill, emissions monitoring data have at least three inherent limitations to the environmental health professional, as discussed below.

First, like soil gas monitoring data, emissions monitoring data at landfills characterize environmental conditions on site, often far from where residents might be exposed to contaminants. Therefore, the emissions data might be a poor indicator of exposure concentrations. Second, emissions data typically (though not always) provide a one-time account or “snapshot” of landfill emissions. Because landfill emissions likely exhibit significant seasonal variations, the measured emission rates from one study might not be representative of emissions over the longer term. Third, emissions monitoring studies at landfills usually consider only one or a few of the landfills’ sources. Because many landfills have numerous operations (e.g., composting, waste handling, transportation), each of which emits some pollutants to the air, most emissions monitoring data likely do not characterize the overall emissions from a given landfill.

When considering these limitations, environmental health professionals ultimately must evaluate emissions monitoring data in perspective: the data indicate rates at which landfills release chemicals to the air, and they often indicate the relative quantities of chemical-specific emissions. However, they do not provide a direct measure of breathing zone concentrations. Breathing zone concentrations are characterized only by ambient and indoor air monitoring data.

Where can I get more information about emissions monitoring?

General information about landfill emissions and emissions monitoring can be found in the following resources. In addition, state and federal environmental officials are an excellent resource for site-specific insights.

- Information related to the CAA regulations for municipal solid waste landfills and landfill emissions estimation can be found at **http://www.epa.gov/ttn/uatw/landfill/landflpg.html**. The actual regulatory text, which includes emissions estimation, testing, and monitoring requirements, can be found in 40 CFR Part 60, Subparts Cc and WWW.
- EPA maintains a Web site (**http://www.epa.gov/ttn/emc)** with general information about emissions sampling methodologies; some of this information is specific to emissions monitoring at landfills.
- EPA. 1998. Guidance on Collection of Emissions Data to Support Site-specific Risk Assessments at Hazardous Waste Combustion Facilities. EPA/530-D-98-002.
- Scotto RL, Minnich TR, and Leo MR. 1991. A Method for Estimating VOC Emission Rates from Area Sources Using Remote Optical Sensing, in the Proceedings of the AWMA/EPA International Symposium on the Measurement of Toxic and Related Air Pollutants, Durham, NC. May 1991.

Ambient Air Monitoring

Unlike most soil gas monitoring data and emissions monitoring data, which do not characterize levels of contamination that residents are inhaling, ambient air monitoring data can provide a better characterization of gases in the breathing zone. These data, together with indoor air monitoring data (when available), are most useful for evaluating the inhalation exposure pathway at landfill sites. The following discussion presents important background information about this type of monitoring.

What is ambient air monitoring?

Ambient air monitoring measures levels of contamination in outdoor air, or in the air that people breathe. The levels of pollution measured in the ambient air reflect the combined influences of many different nearby sources, and even some distant ones.

Why is ambient air monitored at or near landfills?

The main reason ambient air monitoring is performed at or near landfills is to evaluate worker and community exposure concerns regarding releases of toxic chemicals to the air. However, because federal regulations currently do not require ambient air monitoring to be performed in the vicinity of municipal solid waste landfills, no ambient air monitoring data are available for many landfills. This is especially true for smaller landfills and those that have not generated extensive community health concerns.

In some cases, a landfill may be considered a hazardous waste site under federal and state regulations. At these sites, regulatory agencies or the landfill owner and operator may collect ambient air data. At other landfills, states may operate ambient air monitoring stations near landfills to measure concentrations of some or all of EPA’s criteria pollutants (carbon monoxide, lead, nitrogen dioxide, ozone, particulate matter, and sulfur dioxide). If organic compounds are of concern, continuous monitoring for total hydrocarbons is also possible (but to obtain speciated data, sampling and analysis is usually needed). These pollutants, however, originate from many sources in addition to landfills, and their monitoring data often are viewed as an indicator of general air quality, rather than as the influence of any one particular source (e.g., a landfill).

How are ambient air concentrations measured?

Ambient air concentrations are generally measured according to specifications set forth in an ambient air monitoring plan. Though the content of these plans varies from project to project, the plans typically address at least the following critical elements of ambient air monitoring:

- ***Chemicals selected for monitoring.*** One of the first decisions environmental professionals make when developing an ambient air monitoring plan is to select the chemicals to be monitored—a decision that is largely influenced by the purpose of conducting monitoring in the first place. For example, at sites where potential exposure to landfill gas is of concern, monitoring typically focuses on NMOCs, rather than on metals or particulate matter. At sites where windblown dust is an issue, monitoring would likely also consider particulate matter.

  Results from soil gas, near-surface, and emissions monitoring data, if available, may be a useful guide for selecting chemicals to consider in air monitoring programs. The programs should attempt to measure as many of the chemicals detected in the soil gas and emissions as possible, but especially the most toxic chemicals with the highest concentrations and emission rates. Table 2-1 (Chapter Two) lists some of the more prevalent NMOCs in landfill gas. The EPA's compilation of Air Pollutant Emissions Factors (known as AP-42), Section 2.4, provides typical concentrations of more than 40 NMOCs and inorganic compounds in MSW landfill gas. If no site-specific data are available, the substances on this list may provide a starting point. Realistically, however, ambient air monitoring for the scores of chemicals that landfills emit is a prohibitively expensive endeavor. From a practical standpoint, selection of chemicals for monitoring is determined by weighing several factors, such as cost, chemical toxicity, and the availability of sampling methods that can reliably measure ambient air concentrations of a given chemical.

- ***Sampling methods.*** After sponsoring many years of research into ambient air monitoring, EPA has approved several different types of sampling and analytical methods for a long list of common air pollutants. For criteria pollutants (carbon monoxide, lead, nitrogen dioxide, ozone, particulate matter, and sulfur dioxide), EPA has published a list of sampling devices that are capable of measuring concentrations both accurately and precisely for comparison to its national ambient air quality standards (NAAQS). Similarly, EPA has published two "compendium documents" that describe in detail the agency's approved methods for measuring ambient air concentrations of certain pollutants, including organic compounds. References to these EPA documents are listed at the end of this chapter. Optical methods, such as FTIR, discussed in the Emissions Monitoring section, may also be useful for ambient monitoring near the boundary of a landfill.

  When possible, use of EPA-approved methods is encouraged, because the approval is based on extensive testing of the accuracy and precision of ambient air monitoring. In some cases, however, EPA-approved methods might not be available for certain chemicals or monitoring frequencies (e.g., the compendium documents do not address many of the continuous sampling devices that are available), and use of other methods might be necessary. In these cases, extra care should be taken to ensure that the selected methods are capable of generating high-quality data.

  The monitoring methods selected for use in a given program determine the detection limits for each chemical. The detection limit is the lowest concentration at which the method can reliably measure a chemical's ambient air concentration. For ambient air monitoring data to be useful to the environmental health official, all efforts should be made to use methods with detection limits that are lower than or comparable to ambient air concentrations that would be of health concern.

- ***Ambient air monitoring locations.*** One of the most important elements of developing an ambient air monitoring program is selecting monitoring locations. With strategically chosen locations, monitoring programs can generate data of great usefulness for the environmental health professional. Poorly chosen locations, in contrast, can cause monitoring programs to generate data that offer little insight into air quality in neighborhoods of concern. In general, monitoring locations are selected according to the goal of the sampling program. If the goal is to address community concerns, monitoring locations should include residential neighborhoods at downwind locations nearest the landfill and other places where people might be exposed to landfill gases (e.g., nearby parks, malls, and schools).

  Many additional concerns should be considered when selecting monitoring locations. For perspective on the extent to which landfill emissions affect air quality, simultaneous monitoring at locations upwind and downwind of the landfill of concern is advised. It is equally as critical to review the surroundings of monitoring stations to ensure that local sources of air pollution will not bias a monitor's readings. As examples, monitoring alongside busy roadways or atop industrial facilities will likely generate results indicative of emissions from these sources, even if a landfill is nearby. Schools, parks, and churches generally make excellent choices for monitoring locations because they have few sources of emissions on their premises, they often have sources of electricity readily available, and they typically are located in or near residential neighborhoods.

- ***Monitoring schedules.*** Ambient air monitoring plans should specify both the frequency and duration of the proposed monitoring, and both factors should be considered when interpreting data. The frequency of monitoring is often determined by the available sampling methods. Continuous methods provide an ongoing account of air quality, but these methods usually measure levels of only one pollutant; periodic monitoring is typically, though not always, conducted by collecting 24-hour averaged samples on either a 6-day or 12-day cycle. These frequencies ensure that ambient air samples will be collected on every day of the week over a long-term program.

  Sometimes 8- or 12-hour sampling is conducted. Though useful for occupational exposures, such as on the landfill, such sampling may miss significant off-site releases affecting nearby residents during non-working hours, such as the predawn hour when landfill gas odors are not diluted and diffused by strong wind.

  The duration of monitoring is also an important consideration. Because landfill emissions might exhibit significant seasonal variations, monitoring for a year or longer is needed to accurately estimate the long-term average concentrations of air pollutants. Further, landfill emissions can change from year to year for various reasons, such as increases or decreases in daily disposal rates, changes in waste mix and moisture, landfill closure, and installation of pollution controls. As a result, monitoring results collected when a landfill actively received wastes might not be representative of air quality after the landfill closes. Use of long-term monitoring at fixed locations, when funds to conduct such monitoring are available, is the best approach for evaluating ongoing effects of landfill air emissions on local air quality.

- ***Data quality parameters.*** In ambient air monitoring plans, data quality objectives will be specified for the program. Data quality objectives provide a goal for exactly how accurate, precise, and complete a data set must be. In general, ambient air monitoring programs should strive to collect and analyze air samples in accordance with their method's data quality specifications. Though these specifications vary from method to method, measurement accuracy and precision of better than 50% is usually feasible for most methods. A sampling completeness (defined as the percent of attempted sampling events that are successful) of better than 90% is desired.

What do ambient air monitoring data tell you?

As noted earlier, ambient air monitoring data characterize levels of contaminants in the air that people breathe. Because these data are almost always the best metric for exposure concentrations at landfill sites, it is extremely important that environmental health professionals interpret ambient air monitoring data critically. At a minimum, you should ask yourself the questions on pages 47 and 48 when reviewing these data to ensure that they are truly representative of exposure concentrations.

Questions To Consider When Reviewing Ambient Air Monitoring Data

Chemicals Selected for Monitoring

- What chemicals were selected for monitoring?
- Do these include the chemicals of concern identified by residents, regulators, and public health officials?
- Do the chemicals selected for monitoring include those expected to be emitted in greatest quantities from the landfill and/or those that are the most toxic chemicals in the emissions?
- Are there any data gaps in the chemicals selected for monitoring?

Sampling Methods

- Were EPA-approved sampling methods selected? If not, why?
- Are the selected methods recommended for measuring the chemicals selected for monitoring?
- Are the selected methods capable of achieving detection limits comparable to or lower than ambient air concentrations that would be of public health concern?

Meteorologic Data

- Is there an on-site meteorologic station providing data on wind direction, speed, rainfall, and atmospheric pressure?
- If there is no on-site meteorologic station, how far away is the closest reporting station and how relevant is the data from that station to the site and community?
- Are there known prevailing wind patterns at the site or in the community that may affect changes in contaminant flow pattern, such as the canyon winds in Southern California or seashore wind patterns?

Ambient Air Monitoring Locations

- Was monitoring performed at both upwind (sometimes labeled *background*) and downwind locations?
- Do you have reason to believe that ambient air concentrations of certain pollutants were higher in residential areas other than those selected for monitoring?
- Are the monitoring locations considerably removed from other emissions sources (e.g., industrial facilities or heavily traveled roadways) that might bias the air quality measurements?

Monitoring Schedules

- Was monitoring continuous or periodic?
- If periodic, what monitoring frequency was selected? Was this frequency sufficient for characterizing fluctuations in emissions from the landfill and other sources?
- Over what duration was monitoring performed?
- Is this duration sufficient for characterizing seasonal fluctuations in air quality?

- Was monitoring performed at a time when landfill emissions were considered to be relatively high (e.g., when the landfill was active) or relatively low (e.g., after emissions controls were installed)?
- Was monitoring performed at any period when people complained about odors, such as predawn hours or evenings?

Data Quality Parameters

- What percent of attempted sampling events were successful?
- How accurate were the reported sampling results?
- How precise were the reported sampling results?

When reviewing monitoring data and considering the questions above, you should remember that ambient air monitoring data characterize levels of contamination that result from a combination of many nearby emissions sources, and these data do not characterize influences from any one source (e.g., a landfill) alone. In fact, ambient air monitoring conducted in urban environments will almost certainly identify elevated concentrations of many chemicals (e.g., benzene and 1,3-butadiene) that originate primarily from mobile sources and emissions from gasoline stations.

Failure to consider these other sources might cause you to reach biased conclusions regarding air quality near landfill sites. Perhaps the best way to determine whether a particular landfill is the primary source of a pollutant is to examine whether ambient air concentrations decrease markedly from a source. Chemicals with concentrations that vary little with changing wind directions or with increased distance from a landfill likely do not originate primarily from the site of concern, though exceptions may exist. As listed below, many sources of information are available to guide you in your efforts to make sense of ambient air monitoring data collected near landfills.

Where can I get more information about ambient air monitoring?

EPA has published numerous references on ambient air monitoring data, a subset of which are listed below. Additionally, environmental health professionals should consult with local and state regulators for their insights on site-specific air quality.

- EPA's list of approved sampling equipment for measuring concentrations of criteria pollutants is available in the document "List of Designated Reference and Equivalent Methods," which can be downloaded from the EPA Web site at: **http://www.epa.gov/ttn/amtic/criteria.html**.
- EPA's compendia of approved sampling and analytical methods for inorganic and organic pollutants can be found in the documents "Compendium of Methods for the Determination of Inorganic Compounds in Ambient Air" (EPA document number EPA/625/R-96/01a, which is available at the Web site **http://www.epa.gov/ttn/amtic/inorg.html**) and "Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air: Second Edition" (EPA document number EPA/625/R-96/01b, available at **http://www.epa.gov/ttn/amtic/airtox.html**).
- Additional information about emerging sampling technologies, such as monitoring over an open path using an FTIR spectrometer, is also documented on the EPA Web site **http://www.epa.gov/ttn/amtic**.

- EPA maintains an extensive database of ambient air monitoring results that have been submitted to the agency over the last 30 years. This database, called the Aerometric Information Retrieval System (AIRS), might include ambient air monitoring data for landfill sites that you will review. General information about accessing this database can be found at **http://www.epa.gov/airsweb**.
- Data summary reports for two of EPA's nationwide ambient air monitoring programs can be found in the "technical guidance" section of the Web site **http://www.epa.gov/ttn/amtic**. Information in these reports can be useful for determining whether concentrations measured at a given site are unusually high or low when compared to concentrations at other locations, but these comparisons should be made with caution.

Indoor Air Monitoring

This section defines indoor air monitoring and how it relates to landfills, discusses why indoor air monitoring might be performed in structures near landfills, and presents information that environmental health professionals should consider when reviewing indoor air monitoring data.

What is indoor air monitoring?

Indoor air monitoring is the measurement of air concentrations of contaminants in indoor or enclosed locations. Sampling locations for indoor air monitoring efforts include, but are not limited to, basements of buildings (residential, commercial, and industrial), living spaces in homes, and office spaces at landfills.

Why is indoor air sampled at or near landfills?

Near some landfills, property owners have expressed concern over indoor air contamination primarily because chemicals in landfill gas can transport directly into structures built on top of areas where soil gas contamination exists. As a result, the reasons for conducting indoor air sampling at or near landfills are generally identical to those for conducting soil gas monitoring (e.g., to meet regulatory requirements, to characterize risks for explosions, and to characterize potential exposures to toxic chemicals). These reasons are briefly reviewed below.

According to EPA's RCRA regulations, owners and operators of landfills subject to these requirements must ensure that the concentration of methane gas does not exceed 25% of the LEL for methane (1.25% by volume) in indoor air samples collected in the facilities' structures. This requirement reflects the fact that methane is explosive within the range of 5% to 15% concentration in air. If methane emissions repeatedly exceed the allowed limit, regulators might require that corrective action be taken, such as landfill gas control measures discussed in Chapter Five. Note, however, that this requirement applies only to on-site structures, and some landfills might be exempt from this requirement.

Though not required by law, indoor air monitoring at structures at or near landfills has been conducted for two other reasons. First, some studies have measured concentrations of methane in off-site structures to characterize the risks for explosion as a result of migration of soil gases beyond landfill property lines. If methane is found in a building, continuous indoor air monitors are available to measure methane concentrations and sound an alarm when methane concentrations approach dangerous levels. However, off-site migration of landfill gases at most municipal solid waste landfills is now detected and corrected as a result of the required perimeter soil gas monitoring, so that this type of indoor air monitoring is not necessary at structures located near many landfills. Second, some studies have measured concentrations of many different NMOCs that are suspected of migrating with landfill gas and into residential properties. These studies are rarely performed at landfills, however, and typically only in cases where evidence of off-site migration of landfill gases is well documented. One instance where this may be true is a landfill that may be designated as a hazardous waste site based on federal or state regulations.

How are indoor air concentrations measured?

Though EPA has conducted research on indoor air monitoring technologies, the agency has not issued recommended or approved methods for such monitoring programs. In theory, the sampling and analytical methods listed for the ambient air monitoring sections can also be used to measure indoor air concentrations, but some of these methods involve the use of bulky equipment that is sometimes not suitable for indoor environments, particularly homes. In these cases, environmental officials might rely on hand-held monitoring devices, surveying methods, or monitoring guidance provided by the National Institute for Occupational Safety and Health (NIOSH) or OSHA for use in occupational settings. Whatever the basis for selecting a particular monitoring method, you should take time to review its technical approach to ensure that it is capable of generating high-quality data.

Other features of indoor air monitoring programs—chemicals selected for monitoring, monitoring locations, monitoring schedules, and data quality parameters—should be reviewed in the same manner as the features of ambient air monitoring programs.

What do indoor air monitoring data tell you?

Indoor air monitoring data characterize levels of contamination in indoor environments. The significance of these data depends largely on the scope of the monitoring program. In cases in which only methane is monitored, for example, the data are useful only for evaluating risks of explosion. In cases in which other chemicals are monitored, the data can be used for evaluating potential health risks. The questions in the box on page 47 and 48 should be considered when making this evaluation.

Additionally, you will need to consider the extent to which other indoor sources (e.g., cigarette smoke, losses from cleaning supplies, and emissions from stoves and furnaces) might have contributed to the measured concentrations. Because indoor sources of contaminants can differ considerably from one house to the next, indoor air monitoring data from a given residence should not be viewed as representative of other residences in the area.

Where can I get more information about indoor air monitoring?

Various federal agencies have published references on indoor air monitoring data, a subset of which are listed below. Additionally, environmental health professionals should consult with local and state regulators for their insights on this issue.

- EPA and NIOSH together published a two-part guidance document on indoor air quality issues. The reports are called “Building Air Quality: Action Plan” (EPA document number 402-K-98-001) and “Building Air Quality: A Guide for Building Owners and Facility Managers” (EPA document number 400-1-91-033). Though these documents primarily include information about managing air quality in large buildings (e.g., office buildings), they also include general information about indoor air quality and considerations for conducting indoor air sampling.

- EPA maintains a Web site (**http://www.epa.gov/iaq/ia-intro.html**) dedicated to indoor air quality issues. This site includes information about air quality issues within a wide range of buildings, including homes, schools, and office buildings.

Air Modeling

What is air modeling?

Over the years, scientists have developed a number of mathematical models that can be used to evaluate how chemical emissions disperse in air. Different models may be used to answer a number of different questions about available data, such as how do contaminants disperse from the source or what is one source's contribution to area-wide contamination. These models may be screening models that with little information can provide very conservative estimates, or they may be refined models that require detailed information to provided more accurate estimates. The level of model uncertainty varies from model to model; however, uncertainties always exist with any model.

Another type of model is an emissions estimation model. If emission monitoring data are not available for a landfill, models may be used to estimate emissions. Models of various complexities exist. EPA's Landfill Gas Emissions Model (LandGEM) is one model that is commonly used to estimate year-by-year landfill gas emission rates (in Mg/year) over the life of the landfill and after closure. It can estimate methane, NMOC, and individual organic compounds including many hazardous air pollutants. Landfill owners use this model to determine if the NSPS/EG rules apply to them, and states use this model for emission inventories. The model requires basic information such as the dates the landfill opened and closed, the amount of waste in place, annual waste acceptance rate, and whether the landfill is in an arid or non-arid climate. Default factors can be used for other model parameters, or site-specific methane generation rate constants and organic compound concentrations can be input if site-specific measurements are available. The results from this or other emission models may be used in air dispersion models to predict exposures concentrations in ambient air as described below.

How can models be used at landfill sites?

At landfill sites where no off-site monitoring data are available, emissions data (measured or calculated) from the landfill may be input into a mathematical model to estimate potential contaminant concentrations in surrounding neighborhoods. Models may also be used to estimate the landfill's contribution to measured air pollution, as was done by ATSDR during its study of the Fresh Kills Landfill in Staten Island, New York. This modeling is most applicable in urban areas where multiple sources may be present. Also, if an emission rate model such as EPA's LandGEM is used, it can predict the increase in emissions over time as more waste is added to an open landfill or the decrease in emissions after a landfill is closed. These values could be input into air models to predict increases and decreases in ambient air concentrations and exposures over a period of years.

What factors should be considered when reviewing models?

It is possible (though not likely) that air modeling was conducted for a landfill site and you may need to review and understand the model results. More likely, you may want to consider conducting air modeling for sites under your review, for example, to estimate exposure doses in surrounding communities. In either instance, there are several factors to consider about models:

- ***Are adequate data available to input into a model?*** At a minimum, landfill gas emission data and on-site meteorologic data should be available for air modeling.
- ***Does the model provide an answer to your questions about landfill gas, its migration, or exposures?***
- ***What are the uncertainties associated with the model?*** Results from screening models may have limited use. Results from models with supporting experimental or measured data are more reliable.

Where can I get more information about models?

A good source of general information is EPA's Support Center for Regulatory Air Models at **http://www.epa.gov/ttn/scram/**. This Web site includes links to EPA's latest version of the Guideline on Air Quality Models; to user guides for different types of models (e.g., screening and refined, simple terrain and complex terrain, and mobile sources and stationary sources); and to meteorologic data sets for locations across the country.

As described above, EPA has developed an air model specifically for estimating the emission rate of gases from landfills. EPA's LandGEM is available at the EPA Unified Air Toxics Web site for the Standards or Performance for Municipal Solid Waste Landfills: **http://www.epa.gov/ttn/uatw/landfill/landflpg.html**.

Additional Resources

State air pollution agencies or hazardous waste management agencies

California Air Resources Board—Ambient Air Quality Monitoring (**http://www.arb.ca.gov/aaqm/aaqm.htm**)

EPA's Office of Solid Waste and Emergency Response (**http://www.epa.gov/swerrims/**) 1999. Municipal Solid Waste Landfills, Volume 1: Summary of the Requirements for the New Source Performance Standards and Emission Guidelines for Municipal Solid Waste Landfills. Office of Air Quality Planning and Standards. Research Triangle Park, NC. EPA-453R/96-004.

EPA. 1994. Seminar Publication: Design, Operation, and Closure of Municipal Solid Waste Landfills. Office of Research and Development. Washington, DC. EPA/625/R-94/008.

MDNR 1999. Missouri Department of Natural Resources, Solid Waste Management Program. Sanitary landfill gas monitoring, technicalbulletin. September 1999. **http://www.dnr.state.mo.us/deq/tap/pub2053.pdf**.

SWANA (Solid Waste Association of North America) (**http://swana.com**)

SWANA. 1997. Landfill Gas Operation and Maintenance Manual of Operation. SR-430-23070. Available by searching the DOE Information Bridge at the Web site **http://www.osti.gov**.

CHAPTER
5 Landfill Gas Control Measures

This chapter presents an overview of common landfill gas control technologies. These technologies include means to collect gases, control and treat gases, and use gases to benefit the community (e.g., to generate electricity or heat buildings). A landfill might need gas control measures for several reasons, including government regulations, odor problems, or uncontrolled releases of gases that could pose safety and health concerns. As an environmental health professional, you are not expected to be able to design and implement a landfill gas control plan. However, you should have a basic understanding of the control options that are available to help prevent or control exposures to landfill gas.

Why would control measures be implemented at a landfill?

Many landfills install gas control measures because of regulatory requirements. The federal government has developed laws and regulations that govern the operation and maintenance of landfills. These regulations have been developed to reduce health and environmental impacts from landfill gas emissions through the reduction of ozone precursors (volatile organic compounds and nitrogen oxides), methane, NMOCs, and odorous compounds. States may also have state-specific landfill regulations, which must be as strict or more strict than the federal regulations. The boxes on the next page review some of the applicable regulations.

As described in Chapter Three, odor complaints or potential safety and health concerns may also prompt landfill gas collection. Sulfide emissions are a common source of landfill odor complaints. At older landfills or at smaller landfills exempt from federal and state regulations, uncontrolled releases of landfill gases can pose potential safety and health concerns (e.g., explosion hazards). In such cases, the landfill might implement landfill gas control measures, even if they are not required by federal or state regulations. Some landfills have also implemented voluntary gas collection and control or treatment systems to recover landfill gas for energy production.

What are the components of a landfill gas control plan?

The goal of a landfill gas control plan is to prevent people from being exposed to landfill gas emissions. This goal can be achieved by either collecting and treating landfill gas at the landfill or by preventing landfill gas from entering buildings and homes in the community. Technologies used to control landfill gas at the landfill or in the community can be applied separately or in combination. Note that the NSPS/EG requires a gas collection and control system design plan for landfills that meet the criteria presented on the next page. The NSPS rule specifies the type of information that must be included and the criteria the collection and control systems must meet.

Federal Requirements Under Subtitle D of Resource Conservation and Recovery Act (RCRA) for Landfill Gas Migration Control

Since October 1979, federal regulations promulgated under Subtitle D of RCRA—which regulates the siting, design, construction, operation, monitoring, and closure of MSW landfills—have required controls on migration of methane in landfill gas. These regulations do not address other components of landfill gas. In 1991, EPA issued standards for landfill design and performance that apply to MSW landfills active on or after October 9, 1993. The standards require methane monitoring and establish performance standards for methane migration control. Monitoring requirements must be met at landfills not only during their operation, but also for a period of 30 years after closure.

Landfills affected by RCRA Subtitle D are required to control gas by establishing a program to periodically check for methane emissions and prevent off-site migration. Landfill owners and operators must ensure that the concentration of methane gas does not exceed:

- 25% of the LEL for methane in the facilities' structures (1.25% by volume)
- The LEL for methane at the facility boundary (5% by volume)

Permitted limits on methane levels reflect the fact that methane is explosive within the range of 5% to 15% concentration in air. If methane emissions exceed the permitted limits, corrective action (i.e., installation of a landfill gas collection system) must be taken. The Subtitle D RCRA regulations for MSW landfills can be found in 40 CFR Part 258, which can be viewed through EPA's Office of Solid Waste Web page at **http://www.access.gpo.gov/nara/cfr/cfrhtml_00/Title_40/40cfr258_00.html**

Federal Requirements Under the Clean Air Act (CAA) Regulations (NSPS/EG)

Under NSPS/EG of the CAA, EPA requires affected landfills to collect and control landfill gas. The NSPS/EG target reductions in the emissions of landfill gas due to odor, possible health effects, and safety concerns. The rules use NMOCs (which contribute to local smog formation) as a surrogate for total landfill gas to determine if control is required. Landfills meeting certain design capacity and emissions criteria are required to collect landfill gas and either flare it or use it for energy. Landfills that meet both of the following criteria must collect and control landfill gas emissions.

- Capacity: design capacity greater than or equal to 2.5 Mg and 2.5 million cubic meters.
- Emissions: annual NMOC emission rate greater than or equal to 50 Mg.

The basic requirements are the same for both existing and new landfills. Existing landfills are defined as landfills that received waste after November 8, 1987, and began construction before May 30, 1991. These are regulated through the EG. New landfills are defined as landfills that began construction, reconstruction, or modification on or after May 30, 1991. These are subject to the NSPS.

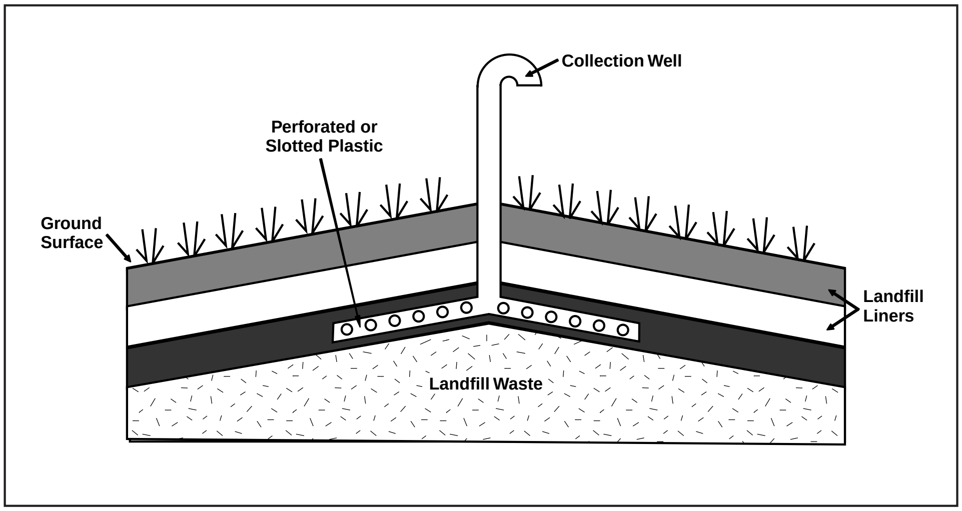
The CAA regulations (NSPS/EG) for MSW landfills can be found in 40 CFR Part 60, Subparts Cc and WWW, available on the Internet at **http://www.access.gpo.gov/nara/cfr/waisidx_00/40cfr60_00.html**. State plans and a federal plan to implement the EG for existing landfills can be found in 40 CFR Part 62. You can also view all Federal Register notices and summary information at **http://www.epa.gov/ttn/uatw/landfill/landflpg.html**.

How is landfill gas collected?

Landfill gas can be collected by either a passive or an active collection system. A typical collection system, either passive or active, is composed of a series of gas collection wells placed throughout the landfill. The number and spacing of the wells depend on landfill-specific characteristics, such as waste volume, density, depth, and area. As gas is generated in the landfill, the collection wells offer preferred pathways for gas migration, as discussed in Chapter Two. Most collection systems are designed with a degree of redundancy to ensure continued operation and protect against system failure. Redundancy in a system may include extra gas collection wells in case one well fails. The system-specific components for passive and active gas collection systems are discussed below.

- ***Passive Gas Collection Systems.*** Passive gas collection systems (Figure 5-1) use existing variations in landfill pressure and gas concentrations to vent landfill gas into the atmosphere or a control system. Passive collection systems can be installed during active operation of a landfill or after closure. Passive systems use collection wells, also referred to as extraction wells, to collect landfill gas. The collection wells are typically constructed of perforated or slotted plastic and are installed vertically throughout the landfill to depths ranging from 50% to 90% of the waste thickness. If groundwater is encountered within the waste, wells end at the groundwater table. Vertical wells are typically installed after the landfill, or a portion of a landfill, has been closed. A passive collection system may also include horizontal wells located below the ground surface to serve as conduits for gas movement within the landfill. Horizontal wells may be appropriate for landfills that need to recover gas promptly (e.g., landfills with subsurface gas migration problems), for deep landfills, or for active landfills. Sometimes, the collection wells vent directly to the atmosphere. Often, the collection wells convey the gas to treatment or control systems (e.g., flares).

Figure 5-1: Passive Gas Collection System



The efficiency of a passive collection system partly depends on how well the gas is contained within the landfill. Gas containment can be controlled and altered by the landfill collection system design. Gas can be contained by using liners on the top, sides, and bottom of the landfill. An impermeable liner (e.g., clay or geosynthetic membranes) will trap landfill gas and can be used to create preferred gas migration pathways. For example, installing an impermeable barrier at the top of a landfill will limit uncontrolled venting to the atmosphere by causing the gas to vent through collection wells rather than the cover.

The efficiency of a passive collection system also depends on environmental conditions, which may or may not be controlled by the system design. When the pressure in the landfill is inadequate to push the gas to the venting device or control device, passive systems fail to remove landfill gas effectively. High barometric pressure, as discussed in Chapter Two, sometimes results in outside air entering the landfill through passive vents that are not routing gas to control devices. For these reasons, passive collection systems are not considered reliable enough for use in areas with a high risk of gas migration, especially where methane can collect to explosive levels in buildings and confined spaces.

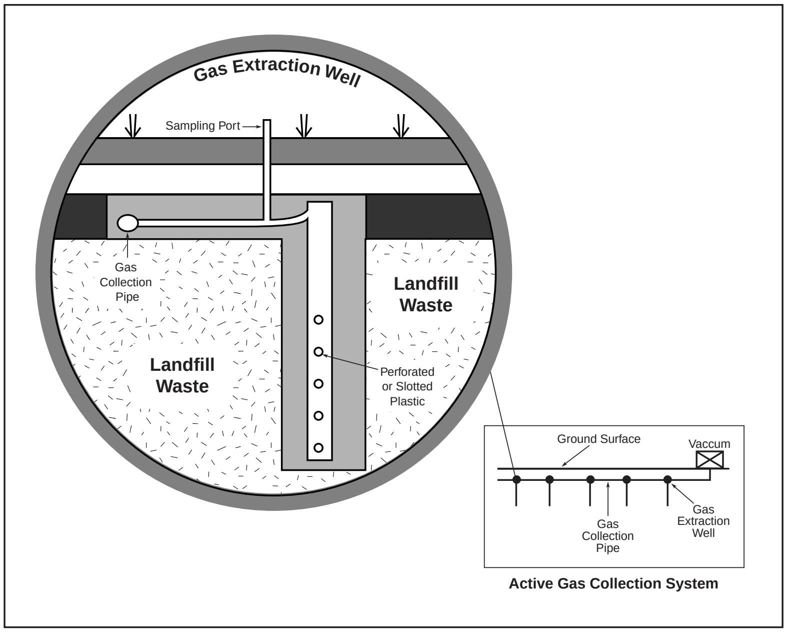
It is fairly common for landfills to flare gas due to odor concerns, for example, even if not the landfill is not subject to regulatory requirements. Passive gas collection systems may be used to comply with the NSPS/EG only at landfills where cells are lined in accordance with Subtitle D of RCRA to prevent gas migration.

Additional references on the effectiveness of passive systems can be found at: **http://www.dnr.state.mo.us/deq/swmp/fgtask7.htm** (Task 7-Gas Cut-Off Trench Effectiveness And Design) and **http://www.dnr.state.mo.us/deq/swmp/fgtask9.htm** (Task 9-Passive Vent To Active System Comparison).

- ***Active Gas Collection.*** Well-designed active collection systems (Figure 5-2) are considered the most effective means of landfill gas collection (EPA 1991). Active gas collection systems include vertical and horizontal gas collection wells similar to passive collection systems. Unlike the gas collection wells in a passive system, however, wells in the active system should have valves to regulate gas flow and to serve as a sampling port. Sampling allows the system operator to measure gas generation, composition, and pressure.

  Active gas collection systems include vacuums or pumps to move gas out of the landfill and piping that connects the collection wells to the vacuum. Vacuums or pumps pull gas from the landfill by creating low pressure within the gas collection wells. The low pressure in the wells creates a preferred migration pathway for the landfill gas. The size, type, and number of vacuums required in an active system to pull the gas from the landfill depend on the amount of gas being produced. With information about landfill gas generation, composition, and pressure, a landfill operator can assess gas production and distribution changes and modify the pumping system and collection well valves to most efficiently run an active gas collection system. The system design should account for future gas management needs, such as those associated with landfill expansion. The box on the next page describes components of an effective active gas collection system.

Figure 5-2: Active Gas Collection System



How Is an Effective Active Gas System Designed?

An effective active gas collection system incorporates the following design elements (EPA 1991):

- Gas-moving equipment, including vacuums and piping, capable of handling the maximum landfill gas generation rate.
- Collection wells placed to capture gas from all areas of the landfill. The number and spacing between each extraction well depends on the waste type, depth, and compaction; the pressure gradients created by the vacuums; and the moisture content of the gas.
- The ability to monitor and adjust flow from individual extraction wells. Inclusion of a valve, pressure gauge, condenser, and sampling port at each collection well allows a landfill operator to monitor and adjust pressure and to measure gas generation and content.

What methods are available to treat landfill gas after collection?

Some passive gas collection systems simply vent landfill gas to the atmosphere without any treatment before release. This may be appropriate if only a small quantity of gas is produced and no people live or work nearby. More commonly, however, the collected landfill gas is controlled and treated to reduce potential safety and health hazards. (A landfill may be required to do so by law, such as the NSPS/EG, as described in Chapter Four.) Common methods to treat landfill gas include combustion and noncombustion technologies, as well as odor control technologies.

- ***Combustion.*** Combustion is the most common technique for controlling and treating landfill gas. Combustion technologies such as flares, incinerators, boilers, gas turbines, and internal combustion engines thermally destroy the compounds in landfill gas. Over 98% destruction of organic compounds is typically achieved. Methane is converted to carbon dioxide, resulting in a large greenhouse gas impact reduction. Combustion or flaring is most efficient when the landfill gas contains at least 20% methane by volume. At this methane concentration, the landfill gas will readily form a combustible mixture with ambient air, so that only an ignition source is needed for operation. At landfills with less than 20% methane by volume, supplemental fuel (e.g., natural gas) is required to operate flares, greatly increasing operating costs. When combustion is used, two different types of flares can be chosen: open or enclosed flares.

— *Open flame flares* (e.g., candle or pipe flares), the simplest flaring technology, consist of a pipe through which the gas is pumped, a pilot light to spark the gas, and a means to regulate the gas flow. The simplicity of the design and operation of an open flame flare is an advantage of this technology. Disadvantages include inefficient combustion, aesthetic complaints, and monitoring difficulties. Sometimes, open flame flares are partially covered to hide the flame from view and improve monitoring accuracy.

— *Enclosed flame flares* are more complex and expensive than open flame flares. Nevertheless, most flares designed today are enclosed, because this design eliminates some of the disadvantages associated with open flame flares. Enclosed flame flares consist of multiple burners enclosed within fire-resistant walls that extend above the flame. Unlike open flame flares, the amount of gas and air entering an enclosed flame flare can be controlled, making combustion more reliable and more efficient.

— *Other enclosed combustion technologies* such as boilers, process heaters, gas turbines, and internal combustion engines can be used not only to efficiently destroy organic compounds in landfill gas, but also to generate useful energy or electricity, as described later in this chapter.

Some public concerns have been raised about whether the combustion of landfill gas may create toxic chemicals. Combustion can create acid gases such as SO_2 and NO_X. The generation of dioxins has also been questioned. EPA investigated the issue of dioxin formation and concluded that the existing data from several landfills did not provide evidence showing significant dioxin formation during landfill gas combustion. Because of the potential imminent health threat from other components of landfill gas, landfill gas destruction in a properly designed and operated control device, such as a flare or energy recovery unit, is preferable to uncontrolled release of landfill gas. Scientists continue to review new information on by-product emissions from landfill gas control devices as it becomes available.

- ***Noncombustion.*** Noncombustion technologies were developed in the 1990s as an alternative to combustion, which produces compounds that contribute to smog, including nitrogen oxides, sulfur oxides, carbon monoxide, and particulate matter. Noncombustion technologies fall into two groups: energy recovery technologies and gas-to-product conversion technologies. Regardless of which noncombustion technology is used, the landfill gas must first undergo pretreatment to remove impurities such as water, NMOCs, and carbon dioxide. Numerous pretreatment methods are available to address the impurities of concern for a specific landfill. After pretreatment, the purified landfill gas is treated by noncombustion technology options.

  — *Energy recovery technologies* use landfill gas to produce energy directly. Currently, the phosphoric acid fuel cell (PAFC) is the only commercially available noncombustion energy recovery technology. Other types of fuel cells (molten carbonate, solid oxide, and solid polymer) are still under development. The PAFC system consists of landfill gas collection and pretreatment, a fuel cell processing system, fuel cell stacks, and a power conditioning system. Several chemical reactions occur within this system to create water, electricity, heat, and waste gases. The waste gases are destroyed in a flare.

  - *Gas-to-product conversion technologies* focus on converting landfill gas into commercial products, such as compressed natural gas, methanol, purified carbon dioxide and methane, or liquefied natural gas. The processes used to produce each of these products varies, but each includes landfill gas collection, pretreatment, and chemical reactions and/or purification techniques. Some of the processes use flares to destroy gaseous wastes.

- ***Odor Control Technologies.*** Odor control technologies prevent odor-causing gases from leaving the landfill. Installing a *landfill cover* will prevent odors from newly deposited waste or from gases produced during bacterial decomposition. Covering a landfill daily with soil can help reduce odors from newly deposited wastes. More extensive covers are installed at landfill closure to prevent moisture from infiltrating the refuse and encouraging bacterial growth and decomposition. Vegetative growth on the landfill cover also reduces odors. *Flaring* is another technique that can eliminate landfill gas odors by thermally destroying the odor-causing gases. *Venting* landfill gas through a filter is another technology used to reduce odors. Landfill gas is collected and vented through a filter of bacterial slime. As long as oxygen is present, bacteria will decompose landfill gas under aerobic conditions, producing carbon dioxide and water. See the example below of odor controls used at a landfill in California.

Odor Control at the Calabasas Landfill

The Calabasas Landfill, serving 1.4 million people in the Los Angeles area, received approximately 17 million tons of waste from its inception in 1961 through December 1995, when the County of Los Angeles passed an ordinance limiting its use.

Beginning in the mid-1980s, an active landfill gas collection system was installed in phases. The system consists of a network of vertical wells and horizontal trenches placed throughout the refuse fill. A vacuum is applied to the system of wells and trenches to draw the gas into the collection system. The collected gas is routed to a flare station and combusted in flares.

The gas collection system, along with rejection of odorous loads and application of daily cover, is a primary means of controlling odor at the landfill. As a result of these measures, the facility received only one odor complaint during 1995 (NPS 1997).

What methods are available to control landfill gas if it reaches nearby structures?

Under certain conditions, landfill gas migrating underground from the landfill to the surrounding community could present safety and health hazards, such as explosion or asphyxiation hazards. (see Chapter Three for a more detailed discussion of these hazards.) Once landfill gas reaches a building or home, it can enter the structure through a number of available pathways (as shown in Chapter Three, Figure 3-1).

To prevent landfill gas from entering buildings, controlling the gas at the source (the landfill) is the preferred approach. However, several simple community-based or structure-based controls are available to reduce the gas entry pathways and limit indoor migration of gas. If a landfill gas problem is anticipated before construction, control strategies can be incorporated into the building design. If not, alterations to the finished structure might be needed. The two basic approaches to preventing gases from entering a structure include controlling the gas pressure and eliminating available entry pathways or leaks. Regardless of the methods used to prevent or reduce landfill gas entry, continuous methane monitors with appropriate alarms should be strategically placed in buildings where accumulation of explosive levels of landfills gases is possible. The methane monitors and engineering controls should have a frequent safety check and maintenance program to ensure proper function. The box below details the limitations of different landfill gas control options.

- ***Gas Pressure Controls.*** If gas pressure is lower inside a building or structure than it is in the surrounding soils, gas will flow into the building or structure. Controlling gas pressure, therefore, can prevent gas migration indoors. Some techniques to control gas pressure include passive or active venting to reduce gas concentrations under the house, venting around the perimeter of the house, and crawl-space venting. Some of these techniques, however, may require pumps with maintenance and energy requirements.
- ***Leakage Area Controls.*** Another strategy to prevent gas from entering a building or structure is to reduce or eliminate entry pathways. Gas can leak into a building or structure through cracks, gaps, drainage pipes, fireplace air vents, and air conditioning or duct work. Improving plumbing and caulking in a basement to reduce cracks and gaps will reduce entry pathways. These options, however, may only partially address indoor

What Are the Limitations of the Landfill Gas Control Options?

Landfill Gas Collection Technologies

Active venting

- Effectiveness depends on proper placement of system to gas source.
- Improper operation and monitoring potentially creates aerobic conditions that may lead to piping deformation and subsurface fires.
- Requires monitoring and maintenance.

Passive venting

- Most effective using shallow trenches.
- Not completely effective for petroleum-based vapors.

Community Control Technologies

Gas Pressure Controls

- Crawl space venting requires maintenance, and performance data are limited.
- Passive venting is effective only with low underground gas concentrations.
- Active venting may require maintenance.

Leakage Area Controls

- Plumbing corrections may only partially remedy the problem.
- Use of sealing, caulking, and liners has had limited success.

gas migration. Another control option is to install a low-permeability liner around the basement or underground portion of the building.

Are there any beneficial uses for collected landfill gas?

Landfill gas is the single largest source of man-made methane emissions in the United States, contributing to almost 40% of methane emissions each year (EPA 1996). Consequently, a growing trend at landfills across the country is to use recovered methane gas from landfills as an energy source. Collecting landfill gas for energy use greatly reduces the risk of explosions, provides financial benefits for the community, conserves other energy resources, and potentially reduces the risk of global climate change.

Currently in the United States, approximately 325 landfill gas energy recovery projects prevent emissions of over 150 billion cubic feet of methane per year (or more than 300 billion cubic feet of landfill gas). Approximately 220 of these projects generate electricity, producing a total of more than 900 megawatts per year. Another 68 projects are under construction in 2001, and more than 150 additional projects are in the planning stages. Previous studies by EPA and the Electric Power Research Institute estimate that up to 750 of the landfills in the United States could profitably recover and use their methane emissions (DOE n.d.a.).

What landfills can be used for gas recovery and how is energy generated from landfill gas?

The feasibility of installing a landfill gas recovery system depends on factors such as landfill gas generation rates, the availability of users, and the potential environmental impacts. Many different landfill types with varying gas production rates and composition can support energy recovery projects. There are, however, several guidelines to consider when assessing the feasibility of generating energy from landfill gas. The box on the following page lists some of these guidelines.

If feasible, energy recovery can be implemented by use of combustion- or noncombustion-based technologies. Combustion-based technologies that recover energy include boilers, process heaters, gas turbines, and internal combustion engines. For example, landfill gas can be piped to a nearby industry, commercial business, school or government building where it is combusted in a boiler to provide steam for an industrial process or heat for a building. It may be combusted in an industrial process heater to provide heat for a chemical reaction. Turbines and internal combustion engines can combust landfill gas to generate electricity. The electricity can be used to meet power needs at the landfill or a nearby facility, or the electricity may be sold to the power grid.

The choice of which type of combustion device to use (e.g., boiler, gas turbine, internal combustion engine) depends on what users are located near the landfill, site-specific technical and economic considerations, and sometimes environmental impacts. For example, internal combustion engines are often less costly than gas turbines for smaller landfills. However, these engines may emit more NO_X, which contributes to ozone formation. If the landfill is in a nonattainment area for ozone, then NO_X emissions may be a barrier to using an internal combustion engine.

Information on typical emissions from various combustion devices can be found in EPA’s compilation of air pollutant emission factors (AP-42). Information on these technologies can also be found in the background document for the NSPS/EG (EPA 1991) and on the Landfill Methane Outreach Program (LMOP) Web site at **http://www.epa.gov/lmop**.

What Are Some Factors Important For Landfill Gas Recovery?

Landfill gas recovery systems cite the following factors as guidelines important for economically feasible landfill gas recovery projects. However, new technologies are becoming available that have allowed successful projects at smaller landfills. For example, smaller landfills can generate enough gas to heat an on-site greenhouse or to use a microturbine to generate a small amount of electricity. Various federal and state incentives (e.g., grants, loans, tax credits, renewable energy purchase requirements) can also enhance the economic feasibility of landfill gas recovery projects.

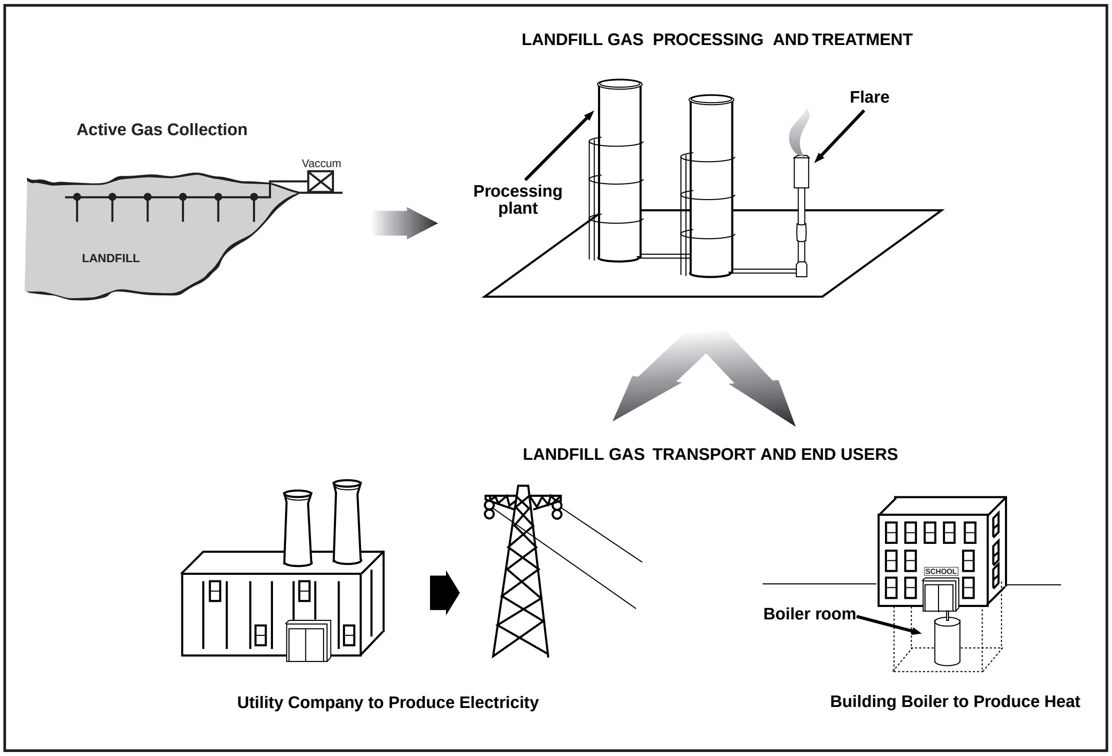
- The amount of waste in place at a landfill is greater than approximately 1 million tons.
- The waste is greater than 35 feet deep and is stable enough for well installation.
- The landfill area is greater than 35 acres.
- The landfill is composed of refuse that can generate large quantities of landfill gas composed of 35% or more of methane. An industry guideline states that gas recovery is economically viable at landfills with gas generation rates of 1 million cubic feet per day (EPA 1996).
- If a landfill is still open, active landfill operation will continue for several more years.
- If a landfill is already closed, a short time (no more than a few years) has elapsed since closure.
- The climate is conducive to gas production (very cold or very dry climates can inhibit gas production).
- The energy user is located nearby or in an area accessible to the landfill.

Noncombustion energy recovery systems are also available, but are not used as widely. Fuel cells are a promising new technology for producing energy from landfill gas that does not involve combustion. This technology has been demonstrated and in the future may become more economically competitive with other options. One option that does not involve combustion of landfill gas at or near the landfill is purifying the landfill gas to remove constituents other than methane, producing a high British thermal unit (Btu) gas that can be sold as pipeline quality natural gas. While the high Btu gas is eventually combusted, it would not contribute to any emissions near the landfill. Another option is using compressed landfill gas as a vehicle fuel.

Both combustion and noncombustion energy recovery systems have three basic components: (1) a gas collection system; (2) a gas processing, treatment, and conversion system; and (3) a means to transport the gas or final product to the user (Figure 5-3). Gas is collected from the landfill by the use of active vents. It is then transported to a central point for processing. Processing requirements vary, depending on the gas composition and the intended use, but typically include a series of chemical reactions or filters to remove impurities. For direct use of landfill gas in boilers, minimal treatment is required. For landfill gas injection into a natural gas pipeline, extensive treatment is necessary to remove carbon dioxide. At a minimum, the gas is filtered to remove any particles and water that may be suspended in the gas stream.

Some examples of successful landfill gas to energy projects are presented in the box on page 63. For more information about landfill gas-to-energy projects, visit the EPA's Landfill Methane Outreach Program (LMOP) Web site at **http://www.epa.gov/lmop**.

Figure 5-3: Landfill Gas Recovery System



Reusing Landfill Gas: Success Stories

Below are some examples of how gas collected from landfills is being reused for power.

- In Raleigh, North Carolina, Ajinomoto Pharmaceutical Company has used landfill gas as fuel in boilers at its facility since 1989. The steam produced by the boilers is used to heat the facility and warm pharmaceutical cultures. This project has prevented pollution equivalent to removing more than 23,000 cars from the road.
- In Pittsburgh, Pennsylvania, Lucent Technologies saves $100,000 a year on fuel bills by using landfill gas to generate steam for space heating and hot water.
- The City of Riverview, Michigan, works with the local utility, Detroit Energy, to recover landfill gas and create electricity with two gas turbines. The project generates enough power to meet the energy needs of more than 3,700 homes.
- The Los Angeles County Sanitation District in California has succeeded in turning landfill gas into a clean alternative vehicle fuel. Landfill gas is compressed to produce enough fuel per day to run an 11-vehicle fleet, ranging from passenger vans to large on-road tractors.
- Pattonville High School in Maryland Heights, Missouri, is located within 1 mile of a municipal solid waste landfill. The landfill supplies methane gas to heat the 4,000-square-foot high school, saving the Pattonville School District thousands of dollars in annual heating costs. Pattonville High School was the first high school to use landfill gas as its source of heat (CNN 1997)

Additional Resources

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CHAPTER 6

Communication

This chapter provides some basic guidelines for communicating information about landfill gas issues. People who live or work near a landfill may pose a variety of questions and concerns to local or state environmental health professionals about landfill gas. For example:

- What is that odor coming from the landfill? Will it make me or my children sick?
- Will air emissions from the landfill contaminate nearby homes and schools?
- Can explosive gases travel from the landfill to basements of neighboring homes?
- I grew up next to a landfill. Am I likely to get cancer or some other illness?
- Are there more health problems in this community because of the landfill?
- How do I know if landfill gas is entering my home or other buildings?
- What are you doing about this problem?

Over the last decade, an extensive body of research has addressed the best ways for environmental health professionals to respond to community members asking questions such as these. ATSDR has drawn from this work to assemble a *Primer on Health Risk Communication and Practices* and *An Evaluation Primer on Health Risk Communication Programs and Outcomes*. Both of these resources are available on the Internet (see the end of this chapter for Web sites and other reference information). This chapter draws from these primers and other resources to help you respond to community concerns and develop a proactive approach to communicating with community members about landfill gas issues. Appendix E provides some examples of fact sheets and newsletters produced to help communicate with community members to address their concerns.

Basic Guidelines for Health Risk Communication

The goal of risk communication should be to promote development of an informed public that is involved, reasonable, thoughtful, solution-oriented, and collaborative. The basic guidelines (adapted from EPA 1992 and 1991; Chess et al. 1988) described below for achieving this goal might appear to be simple common sense, but they are often ignored. When this happens, the consequences can be severe, as illustrated by the case study on the West Covina dump, described later in this chapter. Putting the following guidelines into practice can greatly improve efforts to communicate with the public.

Accept and involve the public as a partner. Effective communication about landfill gas issues depends on developing and maintaining an ongoing relationship with those who live and work near the landfill. In other words, good communication is neither a one-way nor a one-time transmission of information; it involves listening to community members, responding to their concerns, involving them in providing input, and, to the extent possible, involving the community in investigating the problem and devising solutions. Community involvement is key for a number of reasons:

- People are entitled to participate in decisions about issues that directly affect their lives.
- Input from the community can help your agency make better decisions and streamline your efforts.
- Involvement in the process leads to greater understanding of—and more appropriate reaction to—a particular risk.
- Those who are affected by a problem bring different variables and viewpoints to the problem-solving equation.
- Cooperation increases credibility and support.
- Battles that erode public confidence and agency resources are more likely when community input is not sought or considered.

Basic guidelines for involving the public include:

- Involve the community and all other parties that have an interest in the issue at the earliest stage possible. Keep in mind that you work for the public and that the public can make or break your initiatives.
- Clarify the public’s role from the outset.
- Clarify your agency’s limitations and range of activities early on.
- Acknowledge situations where the agency can give the community only limited say in how to proceed.
- Learn from the communities what type of involvement they prefer. For example, at the Danbury landfill, described later in this chapter, officials expanded the landfill closure plans in response to citizen concerns and involved a local citizens group in the monitoring, selection of closure options, and other aspects of the landfill.

Identify and respond to the community’s specific concerns and needs. A community consists of a mosaic of diverse “publics” with different needs and interests. These publics may include, for example, communities from different neighborhoods or towns, activists, health care providers, elected officials, and so on. One of the most important steps in effective communication is to identify and get to know these various publics by providing opportunities for dialogue and exchange. This can be done in a number of ways, including holding meetings and availability sessions during which the public can meet one-on-one with agency representatives, meeting with representatives of various groups, and providing hotlines or Web sites through which community members can express concerns. The goals of these interactions is to begin building relationships and trust with community members, to listen to and fully understand their needs and concerns, to learn what the community already knows and what they want to know about the landfill, and to learn when and how the community would like to be communicated with.

Guidelines for identifying community concerns include:

- Do not make assumptions about what people know, think, or want done. Take the time to find out what people are thinking by letting all parties with an interest in the issue be heard.
- Try to identify the various interests in a situation at the beginning and meet with representatives of each interest informally.
- Make sure all affected groups are represented.
- Recognize the strengths and weaknesses of citizen advisory groups.
- Deal with everybody equally and fairly.
- Find out from communities how they like to get information (e.g., in meetings, through mailings or regular newsletters, on the Internet, at the local library, through the local newspaper, etc.). Try to accommodate their needs. At the Danbury landfill, for example, officials used a wide variety of channels to communicate with a variety of publics, including citizens groups, health professionals, and schoolchildren. Copies of some of the fact sheets produced to communicate with residents near the Danbury landfill are provided in Appendix E.
- Identify with your audience. Put yourself in its place. Recognize and empathize with the audience’s emotions. (See below for additional guidance.)
- When appropriate, develop alternatives to large public meetings. In particular, hold smaller, more informal meetings whenever possible. Consider breaking larger groups into smaller ones.
- Be clear about the goals of the meeting. If you cannot adequately fulfill a resident’s request for a meeting, propose alternatives.
- In certain situations, one-to-one communication may work best.

Be honest, frank, and open. People often care more about honesty, trust, credibility, competence, control, fairness, caring, and compassion than about statistics and details. Trust and credibility are difficult to obtain; once lost, they are even more difficult to regain completely. Guidelines for building trust and credibility include:

- State your credentials, but do not ask or expect to be trusted.
- If you do not know an answer or are uncertain, acknowledge that but get back to people as soon as possible. (See additional guidance later in this chapter.)
- Do not hesitate to admit mistakes.
- Disclose risk information as soon as possible and do not minimize or exaggerate the level of risk.
- Try to share more information, not less, or people may think you are hiding something.

Plan carefully and evaluate your efforts. Successful planning and evaluation entails the following six elements: (1) begin with clear, explicit objectives; (2) evaluate the information you have about risks by assessing the strengths and weaknesses of the data; (3) identify and address the particular interests of different groups with which you work; (4) train your staff, including technical staff, in communication skills; (5) practice and test your messages; and (6) evaluate your efforts and learn from your mistakes.

Coordinate and collaborate with other credible sources. Often more than one agency is involved in investigating or responding to a particular health risk situation. In these instances, effective coordination and collaboration among the various agencies is critical to maintaining the credibility of all agencies, because few things make risk communication more difficult than conflicts or public disagreements with other credible sources. Guidelines for effective collaboration include:

- Take the time to coordinate with other organizations or groups. Devote the required effort and resources to the slow, hard work of building bridges with other organizations.

  At landfills where the threat of fire and explosion is a concern, develop an active partnership with the local fire departments. Firefighters are often equipped with combustible gas meters to check for methane gas entry into homes and public buildings.

  Include the local owner/operator of the landfill in technical discussions. Many landfill operators are certified professionals with extensive training and experience in landfill operations, including landfill gas monitoring. They often have technical knowledge and insights that can provide critical support for public health actions.
- Try to issue communications jointly with other sources.

Meet the needs of the media. The members of the media are a key communication channel with the public and a powerful force influencing public perception. You can optimize the chances of fair, efficient, and effective media coverage by following these guidelines:

- Be open with and accessible to reporters.
- Consider the needs of the media. For example, realize that reporters must meet their deadlines. Provide them with timely and readily understandable risk information tailored to the needs of each type of media.
- Prepare in advance and provide background material on complex issues.
- Do not hesitate to follow up on reporters' stories about a landfill site with praise or tactful criticism.
- Try to establish long-term relationships of trust with specific editors and reporters.
- Keep in mind that reporters are frequently more interested in politics than in risk; in simplicity than in complexity; and in danger than in safety.

Recognize that people's values and feelings are a legitimate aspect of environmental health issues and that such concerns may convey valuable information. Respond with compassion. When communicating about the risks of landfill gas, it is important to recognize that, if the public perceives something to be a risk, no matter how minimal technical experts find the risk, the public believes it is a risk. Researchers have identified factors that shape the way the public perceives a risk (EPA 1992). Individuals tend to view a problem as **less risky** if it has the following characteristics: *voluntary, familiar, natural, fair, controlled by self, chronic,* or *not memorable*. The problem may be seen as **more risky** if it is *involuntary, unfamiliar, man-made, unfair, controlled by others, catastrophic,* or *memorable*. The non-technical factors that produce a perception of greater risk have been called the "outrage" dimension of risk, because these factors tend to produce feelings of outrage in people. Handling people's emotions about risk with respect and compassion is critical to developing trust. Guidelines for doing so include:

- Provide a forum for people to air their feelings.

- Be sensitive to norms, such as speech and dress.
- Listen to people when they express their values and feelings.
- Acknowledge people's feelings about an issue—anxiety, fear, anger, outrage, and helplessness—and respond to their emotions. Do not merely follow with data. Always try to include a discussion of actions that are under way or can be taken. Tell people what you cannot do. Promise only what you can do, and be sure to do what you promise.
- Show respect by developing a system to respond promptly to calls from community residents.
- Recognize and be honest about the values incorporated in agency decisions.
- Be aware of your own values and feelings about an issue and how they affect you.

How can you best communicate scientific information?

Experience has shown that the following guidelines can help in communicating scientific information to the public (adapted from EPA 1992):

- When addressing individuals or large groups, use simple, non-technical language.
- Do not underestimate the public's ability to assimilate technical information. If there is a compelling reason for people to learn new information, they generally will make the effort.
- Try to determine what technical information people need, and in what form. This means taking the time to know your audience. Be willing to summarize information your audience needs, rather than to present everything you know.
- Communicate on a personal level by using vivid, concrete images or examples and anecdotes that make technical data come alive. Be sure to cover people's specific concerns.
- Anticipate and respond to people's concerns about personal risk. Remember the factors driving the public's concern.
- Be sure to provide adequate background when explaining risk numbers and to use non-technical language as much as possible. For example, use simple analogies such as "1 ppm is like a BB in a boxcar."
- Provide information responsive to public concerns that is neither too complex nor patronizing.
- Put data in perspective and try to express the risks in different ways.
- Use language consistent with the expertise of your audience and avoid the temptation to use jargon (for example, avoid describing a method for estimating risk as "conservative").
- Explain the process you used to determine health and safety risks of landfill gas. Be willing to discuss uncertainties. Reviewing this process with the public is important to demonstrate that risk numbers are not derived from a "black box."
- Whenever possible, use graphics and visual aids to make your points.
- Work with other credible experts to present the information.
- Use caution when comparing landfill risks to other risks. Though risks may appear com-

parable from a scientific standpoint, they rarely are so to an outraged audience. For example, it is usually inappropriate to compare a voluntary activity, such as smoking or driving a car, to an involuntary one, such as living near an odorous landfill. People will often view these as non-comparable and will respond negatively to attempts to link them.

- Do not introduce more than three new concepts at a time.

What if you don't know the answer?

As you address concerns from the community, you might be faced with questions you cannot answer. Perhaps you have not researched the question yet ("Has the landfill ever accepted waste from ABC Chemical Company?") or the question cannot be answered conclusively ("Are the respiratory illnesses in our community caused by breathing chemicals in the landfill gas?") Risk communication experts offer seven tips on dealing with uncertainty (Chess et al. 1988):

Acknowledge uncertainty. Agency experts have a natural tendency to feel that they should have all of the answers and to be defensive when they do not. Rather than trying to cover up what you are unsure of, try to explain uncertainties before you are confronted with them. Never guess or make up an answer because you feel pressured; this is a sure way of losing any trust or credibility you have established.

Give people background about scientific uncertainties. People need to understand the risk assessment process so that they understand that uncertainty is an inherent part of the process. Such an explanation will help people to understand how a risk estimate can be based on the best scientific data available, yet still be uncertain. Because the risk estimate will be more sensitive to choices of certain assumptions, the risk messages should state which assumptions were used, why they were selected, and what difference they make in the risk estimate. Be sure to provide these explanations in English as simple and plain as possible.

Be specific about what you are doing to find the answers. You do not want people to equate your statement of "I don't know" with "I don't care" or "I am incompetent." Explain the process; let people know what has been done, is being done, and will be done to resolve uncertainties. Explain why resolving uncertainties takes time, and how conservative assumptions are built into the standard-setting or permitting process to account for uncertainty until more is known. Such an explanation is credible if it is provided early, when the process itself is explained. An explanation also involves describing how various uncertainties affect risk estimates and which ones are the most significant for a particular issue. To maintain credibility, be sure to balance uncertainties with certainties.

Consider involving the public in resolving the uncertainty. Involving the public in dealing with uncertainty is typically viewed by the public as fairer and could lead to better solutions. Welcoming community suggestions about ways of improving risk assessment data can elicit technical information (e.g., exposure routes that may have been overlooked) and can demonstrate that your agency listens and is responsive. However, be aware that people often are sensitive to "token" gestures. Perceived token gestures undermine credibility.

Stress the protectiveness that is built into the standard-setting and risk assessment processes. Stressing the protective nature of these processes is quite important for maintaining public confidence, because often people do not realize that, in the face of uncertainty, government agencies build in margins of safety to account for the uncertainty and to err on the side of health protection. Without this understanding, people are likely to be concerned about uncertainty because they fear that it leads to their being exposed to greater risk.

If people demand absolute certainty, pay attention to values and other concerns, not just the science. Public demands for certainty and disputes over science often reveal disagreements with agency process, policies, and values. People sometimes feel that they can make more headway with an agency if they talk about science rather than about values, so they may focus on science when they really are concerned about agency judgment calls.

Acknowledge the policy disagreements that arise from uncertainty. In the face of such a disagreement, understand the nature of the disagreement and have the appropriate parties acknowledge the range of opinion. For example, if the disagreement is about science, scientists should explain the differences and discuss science; if the disagreement is about values, discuss values.

A Risk Communication Case Study: West Covina, California

In the late 1960s, much of the hazardous waste from the Los Angeles area was trucked a half-hour away to a 40-acre garbage dump in West Covina. Developers built houses right up against the dump site. Strong odors emanated from the dump, where organic chemicals were mixed with garbage on the theory that bacteria from the garbage would break down the chemicals. However, through this process, methane gas migrated to the surface, carrying a variety of organic chemicals with it.

By the late 1970s, more and more residents were complaining about the odors and asking about possible health effects. In 1981, a study found that vinyl chloride in excess of the state ambient air standard was present in the gases coming into the neighborhood. By 1983, at least nine other potential carcinogens were found in ambient air at the site.

At first, state officials from the California Department of Health Services made many of the mistakes that polarize these situations. They did not create mechanisms for communicating regularly about the problems. Nor did they acknowledge the outrage felt by residents, who had no way to control their exposure to dust, fumes, and odors, and who could not obtain the information they wanted. As a result, when the agency presented a report about risks of chemical exposure, the residents responded with criticism and distrust. To make matters worse, subsequent to the meeting, methane was found at close to explosive levels in houses nearest to the dump. The fire department had to evacuate 19 homes, and it was 4 months before the gas collection system was upgraded and the residents were allowed to return.

Relationships with the community began to improve only when agency staff made a commitment to talk with constituencies in the community and establish positive relationships. Staff members began to work with people trusted by the community's different constituencies—for example, by inviting local activists to review a draft report and sit in on an advisory committee meeting. The agency held additional meetings to listen to concerns and demands of residents. The state could not meet all of these demands, such as the demand for a multimillion dollar exposure assessment, but it did provide a summary of data about all substances to which the community might be exposed and conduct a review of birth certificate data. In these ways, the agency acknowledged the residents' outrage and allowed them a substantial role in suggesting courses of action, thereby establishing a constructive working relationship with the community.

Source: Neutra 1989

The Danbury Landfill—Addressing Community Concerns

Local health departments in Danbury and Bethel, Connecticut, began receiving numerous telephone calls in the summer of 1996 from residents about strong odors from an old Danbury landfill. Residents were concerned about the nuisance aspects of the odor; health symptoms such as itchy, watery eyes, headaches, and increased asthma; and other potential health effects. State and local agencies developed a variety of communications and outreach activities to keep residents informed throughout the process of odor control, site monitoring, and landfill closure activities and to respond to residents' requests for specific health and other information. Outreach activities were phased out as citizen complaints diminished over time. Outreach included:

- Establishing a hotline that provided information and recorded callers' messages.
- Producing fact sheets on "Municipal Waste Landfill Gases" and "Reproductive Health and the Danbury Landfill."
- Distributing biweekly press releases to provide residents with updated information.
- Publishing a newsletter (one issue) jointly produced by the Connecticut Departments of Public Health and Environmental Protection, the Danbury and Bethel Health Departments, and the Bethel Citizens Coalition, with articles by each of these organizations on recent developments and responses to health and environmental issues raised by residents.
- Holding public meetings (two) to provide citizens with the most up-to-date information regarding landfill closure and odor control measures and to respond to questions.
- Hosting a cable TV session with local physicians to provide health information and answer call-in questions from viewers.
- Holding a forum with local physicians (of whom about 25 attended) to make presentations and discuss odor and health issues associated with the landfill. The meeting increased physicians' understanding of the issues and enabled them to better address their patients' concerns. Also, the "Danbury Landfill Update" newsletter (see above) advised residents with medical concerns to see their primary physicians, who could refer them to specialists in environmental medicine for further evaluation.
- Visiting a local school system (the mayor and local health department staff) to make presentations to elementary school and high school students.
- Attending a meeting of a local citizens group that formed in response to the strong odor problem at the landfill to discuss strategies for addressing residents' requests.
- Conducting a tour of the local sewage treatment plant for the Bethel Citizens Group. (At one point, the plant was suspected as a possible source of the hydrogen sulfide odor, which turned out not to be the case.)
- Expanding the landfill closure plans. The initial plan involved closing the landfill with a clay cap over a portion of the landfill. In response to citizen complaints, this plan was expanded to include a gas control and treatment system (on an accelerated schedule); air and additional groundwater monitoring; an odor registry of health complaints; a liner under the landfill to reduce leachate and any potential groundwater contamination; and a cap over the entire landfill area. In addition to state and local health and environmental agencies, the local citizens group was involved in monitoring, selection of closure options, and other aspects of the landfill.

Also see Chapter Three for a discussion of the technical aspects of the Danbury landfill.

Additional Resources

The following variety of resources—from publications to online documents to educational and professional organizations devoted to assisting with the practice of risk communication—are available to help environmental health professionals develop effective risk communication programs:

American Industrial Hygiene Association (AIHA) Founded in 1939, AIHA is an organization of more than 13,000 professional members dedicated to the anticipation, recognition, evaluation, and control of environmental factors arising in or from the workplace that may result in injury, illness, impairment, or affect the well-being of workers and members of the community. As part of a continuing education program, AIHA offers an Effective Risk Communication Training Series. **http://www.aiha.org/distancelearning/html/implementingrisk.htm**.

ATSDR. n.d. Agency for Toxic Substance and Disease Registry. Atlanta: Department of Health and Human Services. Primer on Health Risk Communication Principles and Practices. Available from: **http://www.atsdr.cdc.gov/HEC/primer.html**. Provides a framework for the communication of health risk information to diverse audiences. Discusses issues and guiding principles for communicating health risk and provides specific suggestions for presenting information to the public and interacting effectively with the media.

ATSDR. 1997. Agency for Toxic Substance and Disease Registry. Atlanta: Department of Health and Human Services. An Evaluation Primer on Health Risk Communication Programs and Outcomes. Available from: **http://www.atsdr.cdc.gov/HEC/evalprmr.html**. Can be used to facilitate planning evaluations for risk communication programs. The primer informs decision-makers about what should be communicated, in what form, to whom, and with what expected outcome; identifies performance indicators; and provides guidance on how to use target audience ideas and opinions effectively to shape the risk communication message.

California State University at Northridge (CSUN) The Risk Communication Forum provides links to key sources of environmental health risk information and to fellow professionals in the environmental health community. **http://www.csun.edu/~vchsc006/tom.html#Introduction**.

The Center for Environmental Communication (CEC) at Rutgers brings together university investigators to provide a social science perspective on environmental problem-solving. CEC (formerly the Environmental Communication Research Program) has gained international recognition for responding to environmental communication dilemmas with research, training, and public service. **http://aesop.rutgers.edu/~cec/**.

The Center for Environmental Information (CEI) is a private, nonprofit educational organization founded in Rochester, New York, in 1974. CEI's Environmental Risk Communication Program offers training, resources and skills to enable all parties involved in an environmentally risky situation to work together toward a mutually acceptable outcome.
http://www.rochesterenvironment.org/.

Chess C, Hance BJ, Sandman, PM. 1991. Improving Dialogue With Communities: A Risk Communication Manual for Government. Available from the Center for Environmental Communication (CEC) **http://aesop.rutgers.edu/~cec/** at Rutgers University. Summarizes practical lessons for communicating about environmental issues.

National Association of County and City Health Officials (NACCHO). Don't Hazard a Guess: Addressing Community Health Concerns at Hazardous Waste Sites. A practical hands-on guide. Although the guide addresses hazardous waste sites, much of it is applicable to working with communities on landfill gas issues. Copies are available from NACCHO, Suite 500, 440 First Street NW, Washington, DC 20001-2030; telephone (202) 783-5550, or at **www.naccho.org**.

The National Partnership for Reinventing Government has developed a guidance document, Writing User-Friendly Documents, to help writers avoid producing complicated, jargon-filled documents. **http://www.plainlanguage.gov**.

National Research Council. 1989. Improving Risk Communication. Washington, DC: National Academy Press; 1989. Provides guidance about the process of risk communication, the content of risk messages, and ways to improve risk communication.

The Risk Communication Network The Risk Communication Network is a project initiated by the World Health Organization Europe (WHO Europe) and coordinated by the Centre for Environmental and Risk Management (CERM). The risk communication network staff produces RISKOM, a regular newsletter outlining developments in risk communication throughout Europe and beyond. Network membership and the newsletter are free. **http://www.uea.ac.uk/menu/acad_depts/env/all/resgroup/cerm/rcninfo.htm**.

University of Cincinnati Center for Environmental Communication Studies The mission of the Center is to enhance the understanding and quality of communication processes and practices among citizen, industry, and government participants who form and use environmental and health policies. **http://www.uc.edu/cecs/cecs.html**.

The University of Tennessee College of Communications offers seminars on risk communication. **http://excellent.com.utk.edu/**. Crisis communication links and environmental issues links can be found at **http://excellent.com.utk.edu/~mmmiller/riskcom.html**.

Hotline

Risk Communication Hotline. Responds to questions on risk communications issues and literature, provides information on U.S. EPA's Risk Communication Program, and makes referrals to other related agency sources of information. 202-260-5606, Monday through Friday, 8:30 a.m. to 5:00 p.m., E.S.T.

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APPENDIX A

Acronyms

AIRS	Aerometric Information Retrieval System
ATSDR	Agency for Toxic Substances and Disease Registry
C&D	construction and demolition
CAA	Clean Air Act
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
F	Fahrenheit
FTIR	Fourier transform infrared
IRIS	Integrated Risk Information System
LEL	lower explosive level
LMOP	Landfill Methane Outreach Program
µg/m^3	micrograms per cubic meter
mg/m^3	milligrams per cubic meter
mrl	minimal risk level
MSW	municipal solid waste
NAAQS	National Ambient Air Quality Standards
NIOSH	National Institute for Occupational Safety and Health
NMOC	non-methane organic compounds
NSPS/EG	New Source Performance Standards and Emissions Guidelines
NTIS	National Technical Information Service
OSHA	Occupational Safety and Health Administration
ppb	parts per billion
ppm	parts per million
RBC	risk-based concentration
RCRA	Resource Conservation and Recovery Act
SWANA	Solid Waste Association of North America
UEL	upper explosive limit

APPENDIX B

ATSDR Guidelines

ATSDR Guidelines for Public Health Actions in Response to Landfill Fires

I. Background

Fires in landfills can occur for a variety of reasons in essentially any type of landfill. These types of fires present complex problems for a variety of specialists. The fire service must contain and extinguish an underground fire with limited firefighting options available. The environmental officials are confronted with complex chemical reactions in progress involving unknown chemicals and quantities. The environmental health official must recommend public health actions to reduce the acute and chronic health impacts of a situation that may last for weeks or months.

This document is intended to provide guidance only; it should not be interpreted as mandatory. Deviations from the procedures by the environmental health professional are expected and desired when the situation does not conform to the constraints and assumptions made herein.

II. Assumptions

Unless there is reasonable evidence otherwise, the environmental health professional should assume that chemicals are involved in the fire. The types of chemicals most likely to be involved are consumer products that may include consumer-grade pesticides, organic chemicals (usually from paints or solvents), and inorganic chemicals resulting from consumer-grade cleaners and additives to the organic compounds. The smoke from such a fire will contain virtually any compound disposed of in the landfill and may contain all products of thermal decomposition, depending on the efficiencies of combustion and the vagaries of the landfill fire. Usually, the concentrations of any one of these compounds will not be sufficient to cause acute symptoms; however, the combination of so many chemicals at one time may produce an unknown human reaction. Fine particulates in the smoke may play a role in drawing some of these pollutants deeper into the lungs than would normally be expected. Respiratory irritation is likely. A prudent public health assumption is that some individuals exposed to the smoke will have a preexisting respiratory condition (e.g. asthma, emphysema) that increases the probability of acute health impact.

III. Air Monitoring

The primary concern in the initial stages of a landfill fire is air contamination. Organic contaminants can be assessed in a qualitative manner by use of real-time monitors such as photoionization detectors, flame ionization detectors, or infrared ionization detectors. Quantitative data from use of either high volume or personal air pumps should also be considered, especially for fires expected to last for more than 1 week.

A. Real-Time Air Monitoring

Ionization detectors are broad spectrum devices used to detect primarily volatile organic compounds, although some models of photoionization detectors may detect some inorganic compounds. It is important to know the ionization energy of the detector used. Any compound with a first or second ionization potential below this energy can be detected by the instrument. Any concentration in the range of 1–5 parts per million (ppm) above background is a matter of concern.

Real-time aerosol monitors that measure the amount of total particulates in the air are also available; these instruments are not capable of differentiating between chemical and other particulates. The instrument usually works on the principle of refracted light around the particulates in its sensor. Based on this refracted light, a measure of the amount of particulates in the air is usually obtained in milligrams per cubic meter (mg/m^3). A concentration in the range of 0.35–3.5 mg/m^3 above background is a matter of concern.

If specific contaminants are known or suspected with some degree of confidence to have been placed in the landfill, compound-specific colormetric tubes may also be used to obtain a qualitative amount in the landfill. Concentrations in the range of the recommended exposure limit (REL) should initiate concern. Some compounds commonly associated with landfills are hydrogen sulfide, carbon monoxide, hydrogen chloride, and vinyl chloride.

The technology of real-time air monitoring is rapidly improving. Improved instrumentation quickly becomes available with better detection limits, better specificity, better sensitivity, and more accurate readings, often comparable to laboratory results. If available, these new technologies should be considered in the design of an emergency air monitoring program for a landfill fire.

B. Quantitative Methods

While real-time monitoring provides a qualitative indication of what types of contaminants are present and an estimate of their concentration, quantitative measures should be taken to determine the exact composition and concentration of any plume. This type of data is always more appropriate when available. The preferred method is the use of high-volume air sampling that employs a silicate filter for inorganics in series with a polyurethane foam filter (PUF). Samples should be collected for 4 to 8 hours at a sample rate of approximately 10 liters per minute. The filters are then analyzed in a laboratory according to various standard methodologies.

An alternate method that is less equipment-intensive and that does not require an external power source is personal air pumps. With these instruments, separate pumps or manifolds of the same pump must be used for organic compounds (usually collected with a charcoal tube) and inorganics (usually collected with a silicate filter). Sampling procedures are essentially the same, except that the sample rate is usually less than 2–3 liters per minute.

If the fire is expected to burn for more than a month, consideration should be given to recommending use of one of the air sampling vans developed by EPA and based at the EPA Research Triangle Park, North Carolina, facility or a similar mobile laboratory. These vans sample the air for a variety of compounds and quantitatively analyze at the same time.

In many metropolitan areas, an ambient air monitoring network or station may already be in existence. With little or no modification, these stations may be able to provide quantitative data without additional equipment or operating costs.

As part of the new technology that is affecting the instrumentation fields, new instruments are becoming available that combine the advantages of laboratory accuracy with the mobility and timeliness of real-time instruments. These instruments include portable (i.e., handheld or shoulder carriable) gas chromatographs, infrared-red and/or ultraviolet spectrometers, and bioassay meters. Although there are currently some sacrifices in detection limits, specificity, and sensitivity, the line between field instruments, broad-spectrum devices, and laboratory analysis is rapidly becoming more and more blurred.

With careful consideration, quantitative data may be used to adjust action levels to reflect the actual situation more accurately. Sometimes, the adjustment is to increase the action level, potentially impacting fewer people. At other times, an adjustment can decrease the action level to protect a group previously unknown to be at potential risk.

IV. Rationale for Selection of Action Levels

A. Quantitative Data

Quantitative data should be used if available. If the quantitative data are not readily available, means to acquire these data should be sought to verify the real-time data. Recommendations concerning action levels should be developed as they normally would, according to the exposures present (e.g., people, environment, and contaminants) and the expected duration of the fire.

B. Real-Time Readings from Ionization Detectors

EPA, in its original Standard Operating Safety Guidelines, delineated a method for selecting personal protective equipment (PPE) according to real-time readings of ionization detectors. The following action levels are based on that method. The methodology allows for the uncertainity in using broad-spectrum devices and the relative sensitivity of the instrument for different compounds. The EPA guideline calls for response workers to upgrade to air-purifying respirators at 1 ppm total organics above background and to supplied-air respirators at 5 ppm above background.

If the landfill fire is expected to be of short duration (e.g., no more than a few days), real-time readings of 1 ppm above background levels at the closest downwind residences are probably acceptable. If sustained readings are more than 1 ppm above background, then protection of sensitive populations should be considered. If sustained readings are more than 5 ppm above background at the closest residence, then protection of all residents potentially affected by the plume should be considered. Readings taken upwind of the fire should be considered indicative of background concentrations.

If the landfill fire is expected to be of prolonged duration, protection of all residents should be considered at sustained readings more than 1 ppm above background. With fires of this duration, quantitative data should be obtained.

C. Real-Time Action Levels Based on Total Particulates

Total particulate action levels are based, in part, on the color of the smoke and the suspected contents of the fire. Total particulates are recommended here, rather than fine particulates, because using total particulates avoids the necessity of the air monitoring team's having to stop in one place to collect a reading. The need for lots of data, even if of less than optimum characteristics (e.g., air monitoring versus air sampling, total particulates versus PM-10, etc.), is paramount in estimating the limits of the area and population being affected. Without this information, the response options to the unknown situation become either too extensive or not extensive enough.

If the real-time instrumentation available to the community is more sophisticated than described here or if the ever-increasing technology of real-time meters allows, then more accurate and protective action levels may be considered. However, the speed and mobility of the air monitoring teams should not be unduly sacrificed for this greater specificity and accuracy.

If the smoke is black in color, a significant amount of organic material is likely to be present. Black smoke indicates an increased concentration of soot, which is similar to carbon black, a known human carcinogen. If the smoke is gray or another color, contaminants such as inorganics are likely present; most of these will be acid gases and metallic oxides. The action level of 3.5 mg/m^3 and 0.35 mg/m^3 in the presence of sulfides is based on the OSHA PEL for carbon black and on the case studies of the Great London Fog. The action level of 10 mg/m^3 is based on the American Conference of Governmental Industrial Hygenists (ACGIH) threshold limit value (TLV) for particulates not otherwise classified. The action level of 5 mg/m^3 is based on the occupational standards for various acids. These acids were thought to be more of an acute threat than the metallic oxides, both because they were deemed more likely to be generated and because they were thought to be more mobile in the environment. Because of the variations in the readings of the specific instruments, 5-minute time weighted averages (TWA) are suggested to reduce these variations and to provide an additional safety factor.

If the fire is expected to be of short duration and the color of the smoke is black, protection of sensitive populations should be considered at concentrations above a 5 minute TWA of 0.35 mg/m^3 above background at the closest residence downwind. Protection of general populations should be considered at a 5 minute TWA concentration of 3.5 mg/m^3 or more above background at the closest residence. If sulfide compounds are detected with a colormetric tube or other real-time instrument, then the 5 minute TWA for the general population should be reduced by an order of magnitude to 0.35 mg/m^3 to allow for the known synergistic effects of that combination. If the color of the smoke is other than black, protection of sensitive populations should be considered at concentrations above a 5 minute TWA of 5 mg/m^3 above background. Protection of general populations should be considered at 5 minute TWA concentration of 10 mg/m^3 above background. Again, background concentrations can be indicated by readings upwind of the fire.

If the fire is expected to be of prolonged duration, protection of all residents should be considered when the 5 minute TWA reaches 0.35 mg/m^3 for sooty fires and 5 mg/m^3 for less sooty fires. Again, for fires of this duration, quantitative data should become available.

D. Compound Specific Qualitative Data

When there is real-time information indicating the presence of a specific compound at an estimated concentration, the action levels suggested above should be modified accordingly.

V. Other Public Health Concerns

Not infrequently, landfill fires produce other health issues. These issues include deposition of contaminants from the smoke, runoff from the fire or firefighting operations into residential areas or surface and subterranean water supplies, and bio-uptake of either of these. Such concerns are often overlooked, with good reason, during the crisis; however, they should be addressed after the fire. During the fire, there are often simple measures to reduce these longer term threats, each with various drawbacks and advantages; some of these are discussed below. It is usually best to deal with these issues as soon as time and resource limitations permit; however, there is often time to characterize the situation better and arrive at a more considered and accurate choice.

VI. Other Response Actions

Although response actions are the responsibility of risk managers, at times local health officials may be asked to provide technical assistance to the local fire department. If requested, ATSDR should provide background information to these health officials while referring them to the regional EPA office.

One of the first actions that may be recommended is air plume/smoke suppression by use of a water mist or fog. This option would probably result in a large quantity of potentially contaminated water, which should be contained until sampled and disposed of appropriately. However, the air plume/smoke may be substantially reduced, reducing the threat to downwind residents.

Another action that may be proposed is the application of firefighting foam in an attempt to smother the fire. In most landfills, sufficient subterrean voids exist that render this technique largely ineffective. However, the air plume/smoke may be reduced.

Excavating the burning areas of the landfill may be suggested; this is effective but resource-intensive. As portions of the landfill are excavated, concentrations in the air plume may increase and the constituents may change, causing problems for the protection of public health. This disadvantage is offset by the increased rate of burning and the subsequent reduction of time spent in extraordinary measures to protect the public health.

Allowing the fire to burn itself out may also be suggested. This option can be effective, and it uses the least amount of emergency response resources. However, depending on the duration of the fire, the extraordinary measures to protect the public health may have to remain in place for a prolonged period of time.

Sheltering in place (remaining inside buildings and homes) versus evacuation is essentially a risk management decision. Depending on the air concentrations, sheltering in place for most people is usually effective in these situations; however, voluntary evacuations and corresponding shelters should be offered. If specific persons or population groups are sensitive to the health effects of exposure, environmental health professionals should recommend evacuation rather than sheltering. If a given population is relatively immobile, sheltering-in-place should be considered.
If there is an individual who is both sensitive and relatively immobile, the likelihood of sheltering-in-place's failing must be considered in choosing an alternative. That evaluation can be most effectively accomplished at the scene. If the duration of exposure to smoke from a landfill fire is expected to be longer than a few days or if unusual weather conditions prevent normal dispersion of the contaminants (e.g., a temperature inversion), then evacuation is generally the more protective and best recommended action.

Issues regarding containment of runoff will likely come up. General practice is that the runoff should be contained, analyzed, and disposed of accordingly; however, there will be times when containment is not practicable (e.g., heavy rains), not timely (e.g., water flows too high), or too resource intensive (e.g., too large an area to contain or too deep to dig). In those cases, containment of the harm rather than containment of the polluted runoff may have to be undertaken. Containing the harm may include shutting down water intakes for a period of time, using underflow or overflow dams, or using vacuum truck shuttles. Options to implement these kinds of measures will usually be discussed by the cognizant risk managers. As long as the ultimate plan covers the most likely contingencies and uncertainties and still protects the population at risk, then it is probably acceptable from a public health standpoint.

ATSDR Guidelines for Evaluating Gases Migrating from Landfills

I. Background

Landfills, especially those that were operating before the stringent requirements of the Resource Conservation and Recovery Act (RCRA) became effective, may pose a health problem as they age. The problems center on the gases generated by the decomposition of the waste in the landfill. Most of the health concerns of landfill gases typically focus on the gases other than methane that may be part of the landfill gas “stream” and that can produce health effects at much lower concentrations than the fire and explosion hazard of methane.

This document is intended to provide guidance only; it should not be interpreted as mandatory. Deviation from the procedures by environmental health professionals is expected and desired when the situation does not conform to the constraints and assumptions made in this document.

II. Assumptions

Unless there is reasonable evidence otherwise, environmental health professionals should assume that hazardous substances were disposed of in any landfill that operated near an industrial area before the effective date of RCRA (~1977). If portable instruments indicate combustible gas readings, the combustible constituents of the landfill gas should be considered to be largely methane (~75%), with the remainder being other flammable or combustible vapors or gases such as benzene.

III. Migration Patterns

In general, there are two pathways by which landfill gases may migrate offsite. The first of these is vertically through the cover; the second is horizontally through the soil. The two pathways are not mutually exclusive; the landfill gases will follow the path of least resistance. Consequently, construction details of the landfill and the geology/hydrogeology of the site will have a bearing on this migration pattern.

Typically, vertical migration is not a concern unless structures have been built on the cover or public access is unrestricted. The gases tend to dissipate in the open environment. However, for people living or working on or adjacent to the landfill, the concentration of landfill gases in the ambient air may pose a concern and may contribute to local air quality problems, odor problems, greenhouse effects, and ozone depletion.. If the gases enter a structure built on the landfill cover, the contaminants can collect in the structure, and the resulting concentrations can reach a level of potential health concern. Depending on the size of the structure and the volume of confined space in relation to the volume of landfill gas entering the structure, a fire or explosion hazard could develop.

Horizontal migration is usually a concern, primarily for off-site structures. The landfill gases will follow the horizontal path of least resistance until they find an avenue to the surface. Because a major constituent of landfill gas is methane, that gas will usually be detected first. If the avenue to the surface accesses the open environment, the gases will dissipate, as they do in the vertical migration pathway. If the avenue intercepts a structure, the gases can build up in the structure as described. According to the data collected by EPA, this horizontal migration is usually limited to about 300 meters from the landfill boundary. [1]

IV. Target Compounds

At any disposal site that accepted industrial waste in its lifetime, the list of analytes should be targeted at the industrial wastes and their environmental degradation products. If leachate or groundwater data are available, the results of this analysis should be considered in determining the target compounds of the landfill gas analysis. Whenever an environmental investigation of a landfill has been prompted by odorous compounds and/or explosive gases, the possible presence of toxic substances should be evaluated as well. With all landfills, alkyl benzenes, sulfur compounds (both organosulfides and acid gases), benzene, vinyl chloride, and methane should be included in an analysis. These are common gases that may be associated with industrial wastes, construction and debris waste, consumer products, normal organic wastes, and/or their degradation products.

V. Sampling Strategy and Locations

As with any form of sampling, the objectives of the sampling effort have to be understood prior to a determination of the sampling strategy. For landfill gases, common objectives may be to:

- determine if an fire or explosion hazard exists
- identify the source of odors
- determine if a toxic substance is being released
- determine if a toxic substance is attaining concentrations of health concern

Depending on the issues arising from any given landfill, other objectives not considered here could arise as well.

Sampling locations are selected based on these objectives and the history and construction of the landfill, the location of receptor populations, and other sources of contamination in the area (i.e., control samples or background concentrations). Fire and explosion hazards are usually a concern only when the gases collect in a confined space such as a building or a basement. Odor concerns arise most commonly in ambient outdoor air. Toxic substances may be a concern in both confined spaces and in ambient air, depending on the human exposure pathway and scenario.

Expected migration patterns are commonly used to determine the orientation of the sampling locations. For instance, “downgradient” locations are usually more numerous and the primary focus of the screening effort. However, “upgradient” samples should also be collected for use as a verification of the migration pattern; to determine if “upstream” diffusion is occurring; or for use as a control or background sample in the event that the migration pattern is well known.

Ambient air sampling locations should be designed through use of predicted prevailing weather conditions. However, the air sampling network should be flexible enough to allow sampling stations in any individual sampling effort to be established according to the actual weather conditions encountered on the day of sampling.

VI. Screening Sampling Techniques

A screening effort is usually the first step. Locations for sampling for a screening effort typically should include vents from the landfill, adjacent structures, and simplistic soil gas sampling between the landfill and the structures. Fourier-transformed infrared-red (FTIR) or Ultra-Violet (UVS) sampling (see below) along the boundary of the landfill should also be considered. In addition to monitoring wells and pre-existing source control (i.e., ventilation and/or “flare”) systems, landfill gases may be sampled from cracks in the landfill cover, from leachate “springs,” and from cracks in adjacent structures and paved parking areas.

Several broad spectrum real-time monitors are useful in landfill screening investigations. These monitors include combustible gas indicators (CGI), ionization detectors, and compound-specific monitors (e.g., hydrogen sulfide or sulfur dioxide meters, methane meters, carbon monoxide meters, etc.). These meters are important for detecting changes in the work environment of site investigators and for identifying sampling locations with good prospects of detecting landfill gases. However, the limitations of these monitors need to be clearly understood in any evaluation of the data obtained through their use. For instance, some ionization detectors suffer significant degradation under some conditions common in landfill gases. Methane can reduce the sensitivity of the photoionization detector (PID) by up to 90%[2]. The flame ionization detector (FID) requires enough oxygen in the sampled gas to maintain combustion (oxygen levels > ~ 12% by volume).

For screening efforts, sweep surveys of the landfill surface and adjacent areas by use of FIDs and CGIs to identify areas where fissures and cracks permit landfill gas to escape naturally may be advantageous for locating a well. During the survey, the team must give attention to identifying “flame out,” the emission of methane at such a rate that no oxygen gets to the flame to permit ionization of the methane.

Grab samples are also useful as indicators of potential trouble spots. Grab samples may be collected in Tedlar® bags or in SUMMA® or other evacuated canisters. Using real-time monitors to coordinate the timing, team members may find grab samples useful in evaluating peaks in the emissions. The results of the grab sampling can also be useful in modifying the target analytes of future sampling efforts.

Soil gas sampling, both on the landfill and off-site, can be extremely useful. In a screening effort, this type of sampling is normally accomplished with punchbars to varying depths, usually no more than 10 feet and often no more than 3–5 feet in depth. The punchbars should be deep enough to permit obtaining data below any cap on the landfill. After the sampling, the hole should be resealed to prevent inadvertent creation of a new vent for the landfill gases. Because pressure within the landfill is critical to predicting landfill gas migration, pressure measurements at these locations should also be considered.

FTIR and UVS sampling are spectroscopic sampling techniques that detect and identify contaminants in the air along a straight line (e.g., the boundary of a landfill). UVS is typically set up for specific compounds (usually inorganic gases), but FTIR can be used for multiple compounds (usually organic gases). The principle is that the infrared or UV light is generated and then passed to a receptor in a line-of-sight position along a boundary of concern. The receptor either analyzes the spectrography of the light or reflects it to another receptor, which then does the analysis. This second receptor may be part of the source instrument. The spectroanalysis can identify specific compounds and concentrations in the space between the source and the receptor. However, the units are usually given in a concentration of volume per unit distance (e.g., ppm-m) or mass per area of the beam (e.g., mg/m^2). The identified constituents can be added to the list of target analytes [3].

VII. Landfill Gas Characterization

According to the results of the screening effort, a more comprehensive sampling effort can be planned. Sample locations in this expanded sampling would be designed to better characterize the gas streams at those locations identified in the screening effort, in similar locations, and near sensitive receptors (e.g., adjacent structures).

Any of the standard methods for ambient air, indoor air, and/or soil gas that attain the desired level of detection for the target analytes are appropriate for use in characterizing landfill gases over time. The detection limits should be lower than the concentration of health concern. Use of these limits makes protective allowance for the unavoidable errors of any chemical analysis.

Soil gas wells on the landfill, between the landfill and adjacent structures, and near the structures should be considered in any comprehensive sampling program. These wells should include pressure gauges to determine the gas pressure at their locations. This pressure may be used to predict the migration patterns of landfill gases.

VIII. Evaluation of Sampling Data

The health-based interpretation of any sampling data is dependent on the quality of the data obtained, the method of sample collection, the location of the sample, the media of the sample, and the demographics of the surrounding area. Many of the sampling methods, preferably used in conjunction with grab sampling at times most likely to identify peak (or worst-case) emissions, will provide adequate data to characterize the health implications of landfill gases under the conditions of the sample.

As a landfill ages, the constituents and the relative concentration of the constituents in the gas stream will change over time. As environmental conditions change (e.g., the height of groundwater levels), the migration patterns and possibly the constituents of the gas stream may change. Any evaluation of environmental data is valid only for the information reviewed and the conditions during the sample collection. Therefore, once a potential threat is identified at a landfill, continued monitoring or additional sampling may be necessary. If the threat continues, source controls may be required.

Negative results during a screening effort may not mean the characterization effort can stop. More than one screening effort may be required to permit obtaining adequate data to indicate that the landfill does not pose a threat. Multiple screening efforts are particularly appropriate when a screening's results indicate variations in the gas stream so that certain constituents of the stream may pose a threat in the near future.

Conclusions based on sample results should be limited to the capabilities of the sample methodology and the knowledge available about the landfill; other possible impacts should be explored when they could be a concern. For instance, if explosive gases are the original concern prompting an environmental investigation, the bulk of the explosive gases from most landfills will be methane. If the choice is made to investigate combustible gases by use of a CGI only, any assumption as to the constituents of the gas stream and the relative hazard are not warranted. For example, if the explosive level measured by the CGI was 60% of the lower explosive limit (LEL) for methane (3% by volume), technically no fire or explosion hazard exists according to that data. However, there is also a need to consider the possible presence of other explosive gases; if only 1% of the combustible gas is a flammable vapor other than methane—for example, benzene—the landfill gas may contain approximately 300 ppm benzene (3% = 30,000 ppm X 1% = 300 ppm). This value for benzene is well above the OSHA PEL of 1 ppm (8-hour TWA) [4] and the ATSDR acute minimal risk level of 0.002 ppm [5].

Many of the typical landfill gases, notably the alkyl benzenes and the sulfur compounds (both organosulfides and acid gases), may present an odor problem that can cause adverse health effects such as mucous membrane irritation, respiratory irritation, nausea, and stress. If an individual has a pre-existing health condition (e.g., allergies, respiratory illness), these additional health impacts can be significant.

Line-of-sight remote sensor sampling (i.e., FTIR/UVS) yields results that are given in units of volume per distance or mass per area of the beam. A value of 3 ppm-m may mean that the plume attained 3 ppm spread over 1 meter, 300 ppb over 10 meters, or 300 ppm over a centimeter. There are models that can predict, based on the reported values, the emission rate as well as the concentration that may impact downwind receptors.

Given some information in the form of environmental sample results, the environmental health professional should compare the concentrations in the samples to our current state of knowledge about those compounds detected while considering the plausible human exposure scenarios at the site. Whenever possible, the sample results should correspond to the media under consideration in the exposure scenario (e.g., air samples for inhalation exposures). Good quality empirical data should always supercede theoretical predictions (i.e., models), no matter how accurate the theory may be. The exception to that principle is a situation in which an interference or additional source of contamination exists and affects the empirical data. If the empirical data validates a model at a particular location, then that model can be used with confidence as long as the model's conclusions are periodically verified with environmental data. If the model is valid at one site, it does not necessarily mean the model is valid at all sites.

Sampling of two different media at approximately the same time also has inaccuracies, unless the migration rate from the one media to the other is known to approximate the sample collection time. In the example of soil gas to indoor air, the migration rate would be dependent on such factors as the permeability of the gas through the soil and then through the structure, the pressure of the gas in the soil, possible variations in the migration patterns, and other factors unique to the specific type of soil and the environmental conditions at the time of the sampling (e.g., depth to water, ambient temperature, etc.).

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[3] Scotto RL, Minnich TR, and Leo MR. 1991. A Method for Estimating VOC Emission Rates from Area Sources Using Remote Optical Sensing. IN: The Proceedings of the AWMA/EPA International Symposium on the Measurement of Toxic and Related Air Pollutants, Durham, NC. May.

[4] Code of Federal Regulations, Title 29 Part 1910.1028.

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APPENDIX C

Health Studies Related to Landfill Gas Exposures

This appendix summarizes five studies that were undertaken to assess the potential health effects of landfill gas exposure over the long term:

1. Study of Reproductive Effects from Exposure to Landfill Gas, Montreal, Canada
2. Study of Cancer Incidences Surrounding a Municipal Solid Waste Landfill, Montreal, Canada
3. Study of Cancer Incidences Surrounding Municipal Solid Waste Landfills, New York State
4. A Panel Study of Respiratory Outcomes, Staten Island, New York
5. Risk of Congenital Anomalies near Hazardous Waste Landfill Sites in Europe: the EUROHAZCON Study

1. Study of Reproductive Effects from Exposure to Landfill Gas, Montreal, Canada

Goldberg MS, Goulet L, Riberdy H, and Bonvalot Y. Low birth weight and preterm births among infants born to women living near a municipal solid waste landfill site in Montreal, Quebec. Environ Res.: 69 (1):37-50. 1995.

Researchers in Montreal conducted a study of landfill gas emissions to evaluate potential reproductive impacts from living near a municipal solid waste landfill. The study design included comparing instances of low birth weight, very low birth weight, premature birth, and smallness for gestational age for populations living near the landfill and assumed to be exposed to landfill gases versus reference populations living beyond the area where exposure was assumed. Control or reference areas were selected based on sociodemographic factors. Potential exposures to landfill gas were defined by exposure zones around the landfill site. Sampling data, however, were not available to quantify exposures. Information was gathered from the Quebec birth registration file.

Researchers found that there were elevated instances of low birth weight and smallness for gestational age in the areas where exposure was assumed. No increase in instances of very low birth weight or premature birth was found. The researchers could not definitively conclude whether low birth weight and smallness for gestational age are associated with exposure to landfill gas. The effects of all potentially important confounding factors could not be addressed, and detailed environmental exposure assessments were not available. Researchers recommended that additional studies be conducted to support or refute their evidence.

2. Study of Cancer Incidences Surrounding a Municipal Solid Waste Landfill, Montreal, Canada

Goldberg MS, Al-Homsi N, Goulet L, and Riberdy H. Incidence of cancer among persons living near a municipal solid waste landfill site in Montreal, Quebec. Archives of Environmental Health. 50(6):416-424. Nov/Dec 1995.

Goldberg MS, Seimiatyck J, DeWar R, Desy M, and Riberdy H. Risks of Developing Cancer Relative to Living Near a Municipal Solid Waste Landfill in Montreal, Quebec, Canada. Archives of Environmental Health. 54(4):291-296. July/August 1999.

The Miron Quarry municipal solid waste landfill is located in a heavily populated area. Approximately 100,000 people live within 2 kilometers (1.5 miles). This landfill, which operated between 1968 and the late 1990s, is also the third largest landfill in North America. Because of its proximity to a large residential population, there has been concern that landfill gases released into the air may have impacted public health. Beginning in 1980, landfill gases were collected and flared; however, the collection system was inefficient and combustion was likely incomplete. Therefore, some landfill gases were still entering the ambient air. Sampling from the gas collection system detected 35 chemicals, including the recognized human carcinogens benzene and vinyl chloride and the suspected human carcinogens methylene chloride, chloroform, 1,2-dichloroethane, bromodichloromethane, tetrachloroethylene, 1,4-dichlorobenzene, 1,2- dibromoethane, and carbon tetrachloride.

Because of health concerns, researchers conducted a study to evaluate cancer incidences in populations living near the Miron Quarry landfill. This study was the first of its kind. The researchers established four exposure zones based on distance from the landfill boundary and prevailing wind direction. The researchers also selected four reference zones based on socioeconomic factors where people were not expected to have been exposed to the landfill gas. Researchers used the Quebec Tumor Registry, a population-based cancer registry, to evaluate whether cancer incidence among persons who lived near the site was higher than the incidence in the reference zones during the period 1981 to 1988.

A statistical analysis found that among men living in the exposure zone closest to the site, elevated risks were observed for cancers of the prostate, stomach, liver, and lungs. Among women, rates of stomach cancer and cervix uteri cancer were elevated, but breast cancer incidence was less than expected. The researchers concluded, however, that there are limits to these findings. Quebec residents who were treated outside of Quebec were not included in the tumor registry. To the researchers' knowledge, the reliability of the data retained in the registry has not been investigated. Although monitoring data for gas in the collection system were available, no data regarding contaminant concentrations in ambient air were available. The researchers, therefore, were unable to assess cancer incidence directly in relation to landfill gas concentrations. No information was available regarding residential history, specifically the duration of residence. The researchers also noted that the landfill began operation in 1968, and the study time encompassed 1981 to 1988. Therefore, the maximum latency period was only 20 years, considered a short latency period for solid tumors. Because of the lack of environmental data and other limiting factors, the researchers stated that they were unable to conclude whether the excess cancer risks found in this study represent true associations with exposure to landfill gas or other factors. The researchers recommended additional study.

An additional study was conducted to further evaluate the cancer incidence in the vicinity of the Miron Quarry landfill. Investigators used face-to-face interviews to obtain information about key risk factors. The main limitations of the study were the absence of complete lifetime residential histories, the relatively short period from the first exposure (1968) to cancer onset, and the use of distance measurements to define “exposure” in lieu of actual measurements of exposure. The results of the analyses suggest possible associations between living near the landfill and liver cancer, kidney cancer, pancreatic cancer, and non-Hodgkin’s lymphomas. The statistical evidence is not persuasive, however, according to investigators. This study did not show an excess of stomach cancer. The finding most consistent with the earlier study was the excess risk of liver cancers in high-exposure zones. Without actual exposure data, no strong conclusions can be drawn, but investigators controlled for other risk factors (e.g., alcohol consumption, hepatitis-B virus) and noted the presence of vinyl chloride (a recognized liver carcinogen) in the landfill gas collection system.

3. Study of Cancer Incidences Surrounding Municipal Solid Waste Landfills, New York State

ATSDR. Agency for Toxic Substances and Disease Registry. U.S. Department of Health and Human Services. Investigation of cancer incidence and residence near 38 landfills with soil gas migration conditions, New York State, 1980-1989. Prepared by the New York State Department of Health, Division of Occupational Health and Environmental Epidemiology, Bureau of Environmental and Occupational Epidemiology. PB98-142144. June 1998.

Continuing public concern about cancer rates and exposure to toxic substances, specifically those in landfill gases, prompted the New York Department of Health (NYSDOH) to conduct a study of cancer incidence among people living near landfills.

From the hundreds of landfills located in New York State, NYSDOH selected 38 landfills for inclusion in this study. These landfills were selected because information indicated that gas production and movement could create conditions for possible exposures. Of these landfills, 30 began operation before 1970. These landfills were not lined or capped as they would be if constructed today because New York State and the federal governments did not begin regulating landfills until 1973 and 1976, respectively. Gas collection systems had been installed in 22 of the study landfills at the time of the NYSDOH study. By the end of the 1980s, only three of the study landfills were operating; currently none are active.

At each of the 38 landfills selected for study, NYSDOH identified potential exposure areas and reference areas where no exposure was expected. The potential exposure areas were identified as a ring around the landfill boundary where landfill gas was migrating according to sampling data. For most of the landfills, this area extended 250 feet from the landfill boundary. At four landfills, sampling data indicated that the area of potential exposure should extend 500 feet from the landfill boundary, and at one landfill the area extended 1,000 feet from the landfill boundary. The reference areas were identified as the area within the same zip code as the landfill, but beyond the ring that defined the potential exposure areas.

Data from the New York State Cancer Registry were used to identify leukemia; non-Hodgkin’s lymphoma; and liver, lung, kidney, bladder, and brain cancer cases diagnosed during the 10-year period between 1980 to 1989. Using death certificates files, NYSDOH also identified non-cancer deaths which occurred in the potential exposure areas and reference areas during the same 10-year period. The residential address for each cancer case and each non-cancer death was used to pinpoint the resident locations in relation to the potential exposure areas and reference areas. To determine if higher than expected cancer cases were occurring within the potential exposure areas, NYSDOH compared the proportion of cancer cases to non-cancer deaths in the potential exposure areas to the proportion of cancer cases to non-cancer deaths in the reference areas. Of the 9,020 cancer cases identified, 49 were within the potential exposure areas. Of the 9,169 non-cancer deaths identified, 36 were within the potential exposure areas.

Using a statistical comparison of these results, this study found a statistically significant four-fold elevation of risk for bladder cancer and leukemia for women living in the areas of potential exposure. This means that the statistical tests show that it is very unlikely, but not impossible, that the higher-than-expected number of cases of these two types of cancer in the area of potential exposure occurred just by chance. For the other five cancers examined in females and the seven cancers examined in males, no statistically significant increase in cancer incidence was found.

These results should be viewed with consideration of the study's limitations, including the lack of exposure (type and duration of exposure) and possible confounding factors. It is possible that unidentified personal risk factors, such as smoking or occupation, could have played a role in the findings. In addition, no data were available to confirm that individuals were exposed to landfill gas or what the chemicals were in the landfill gas. Only a person's address at the time of diagnosis was used for mapping his or her location. The length of time people lived at their homes before being diagnosed with cancer was unknown; a person in the study could have recently moved. This is important because of the latency period between the beginning of the cancer's growth and its later appearance and diagnosis. For most cancers, the period of latency is thought to be between 10 and 20 years.

NYDOH concluded that this study does not prove that there is a relationship between living very close to the landfill and female bladder cancer and leukemia. But the study does suggest that there may be an increased risk for these cancers for women who lived within 250 feet of the landfills during the 1960s and 1970s, based on the reporting dates of cancer incidence and the expected latency period. Since the 1960s and 1970s, when individuals may have been exposed, cleanup efforts have changed the conditions at New York State landfills. As a result, this study does not provide information about health risks related to living near landfills today.

To further assess potential cancer effects from living near landfills, NYDOH is conducting additional review of medical records for leukemia and bladder cancer cases for people who lived in the area of potential exposure. A second study is planned using a different group of controls to see if the initial study findings can be verified. The initial study will be updated to include cancers diagnosed through 1994 and will include additional review of data that are relevant to past landfill conditions. Sampling will be conducted at selected landfills to assess current conditions.

4. A Panel Study of Respiratory Outcomes, Staten Island, New York

ATSDR. Agency for Toxic Substances and Disease Registry. A Panel Study of Acute Respiratory Outcomes, Staten Island, New York. Draft Final Report for Public Comment. August 20, 1999.

In the early 1990s, a community member living near the Fresh Kills Municipal Landfill in Staten Island, New York—one of the largest MSW landfills in North America—requested that ATSDR conduct a public health assessment to address health concerns about living near this landfill. Residents questioned if odors and gas emissions from the landfill might be the cause of asthma and other breathing illnesses in the area. To address these concerns, ATSDR conducted a health study of the nearby communities. The study was undertaken to gain a better understanding of the possible health risks posed by the landfill to area residents. ATSDR designed the study to focus on asthma sufferers and assess how hydrogen sulfide concentrations, odors, and proximity of residence to the landfill might affect respiratory function.

A group of more than 150 community residents, ranging in age from 15 through 65 years, reported as having asthma volunteered to participate in the study. Over 80% of the study participants had lived on Staten Island for at least 5 years. For a 6-week period from July through September 1997, when annual landfill emissions tend to be at their peak, study participants completed a daily diary to record perceived odors, measures of respiratory symptoms, and daily activities. Participants also measured their lung function each morning and evening with a peak flow meter. During this same period, ATSDR conducted continuous air monitoring in the study area to assess ambient air concentrations of hydrogen sulfide (a common source of the rotten egg odor), ozone, and particulate matter. Pollen and fungi counts and meteorologic data, which are confounding factors that can influence study results, were also sampled. ATSDR also conducted a separate odor impact survey to provide an independent odor assessment.

ATSDR concluded that the measured levels of hydrogen sulfide and other parameters were not high enough to cause health problems. 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. Results varied throughout the study group by factors such as the participant’s age and how long he or she had suffered from asthma. Laboratory measurements of hydrogen sulfide, however, did not correlate increased hydrogen sulfide concentrations with increased respiratory symptoms or peak flow.

ATSDR concluded that the results of this study suggest that the perception of odors is associated with worsening of respiratory symptoms of some people in the study group. Future investigations of potential health effects associated with the landfill should consider odor issues.

5. Risk of Congenital Anomalies Near Hazardous Waste Landfill Sites in Europe: The EUROHAZCON Study

Dolk H, Vrijheid M, Armstrong B, Abramsky L, Bianchi F, Garne E, et al. Risk of congenital anomalies near hazardous waste landfill sites in Europe: the EUROHAZCON Study. Lancet. 1998; 352: 423-27.

In 1998, researchers in Europe published the results of a study conducted to assess the relationship between residence near a hazardous waste landfill and birth defects. Several research centers in Europe maintain regional-population based registers of congential anomalies (birth defects). These registers also included data on live births, stillbirths, and pregnancy termination after prenatal diagnosis.

To assess the relationship between birth defects and residence near a hazardous waste landfill, the researchers identified 21 landfills in five countries (Belgium, Denmark, France, Italy, and the United Kingdom) that were located in areas covered by the registers. The landfill and an area within a 7-kilometer (km) radius was identified as the study area. The area within a 3-km radius of the landfill was designated as the “proximate” zone and the area between a 3-and 7-km radius of the landfill served as the control zone.

Researchers reviewed the congential anomaly registers for a time period extending from when the register began to at least 5 years after operation of the nearby landfill began to identify study and control cases. Study cases in the proximate zone and control cases in the control zone were identified geographically by the mother's address or postcode at the time of birth. Once data were collected, researchers conducted statistical analyses to evaluate the expected number of birth defect occurrences and the actual number of birth defect occurrences in both the study and control areas.

The study concluded that there was a small, but significant, increased risk of birth defects to babies whose mothers lived within 3 km of a hazardous waste landfill. Neural-tube defects, malformations of the cardiac septa, and malformation of the great arteries and veins had an increased risk of occurrence. Researchers noted that socioeconomic status is a potential, but unlikely, confounding factor in this study. Another, potentially more important confounding factor is the presence of other industrial sites or toxic exposures near landfill sites. This study did not, however, measure actual chemical exposures of women residing near the landfill sites. Researchers felt that direct measure of exposures and birth defects would better establish a causal relationship. Researchers suggested that further study is needed.

APPENDIX

D Wright-Patterson Air Force Base—A Case Study

ATSDR became involved at Wright-Patterson Air Force Base in 1990, at the request of the Environmental Protection Agency (EPA) Region VI. At that time, ATSDR conducted a health consultation to address gases migrating from two closed landfills to a nearby housing area. In 1999, ATSDR returned to Wright-Patterson Air Force Base to complete a public health assessment, which also included an evaluation of exposure to gases from these landfills.

This appendix provides background information about the landfills at Wright-Patterson and describes the sampling, health evaluations, gas control measures, and community involvement conducted at the site. The intent of this case study is to highlight issues and problems that were addressed during the effort to control landfill gas emissions at this site.

Background

Wright-Patterson Air Force Base has operated outside of Dayton, Ohio since the early 1900s. From the late 1940s until the early 1970s, both nonhazardous and hazardous waste from base operations was dumped into two landfills located next to each other and divided by a small stream. The U.S. Air Force closed the landfills in the early 1970s by covering the waste with a soil layer ranging from 1 to 12 feet deep. No other control measures (e.g., liners or impermeable caps) were installed when the landfills were closed, leaving the hazardous materials in the landfills available to migrate from the site. This is common of open dumps, as discussed in Chapter Two.

After closing the landfills, the U.S. Air Force began building military housing on land abutting the landfills. In 1973, military personnel and their families began moving into these multi-family housing units. These families used the landfills as a recreation area, and the U.S. Air Force built a playground on one of the landfills. People living in the housing units may have been exposed to landfills gases seeping from the landfill surface when they were using the landfills for recreation. Landfill gas migrating in ambient air or underground may have also reached people in their homes.

In the 1980s, the landfills began to settle, and one of the housing units had to be demolished because the settling caused structural problems to the home. In 1985, the Ohio Environmental Protection Agency (OEPA) asked the U.S. Air Force to put up a fence and stop recreational use of the landfills because of concerns about people coming in contact with contaminants. The U.S. Air Force complied and began to study the landfill under OEPA's direction.

Monitoring of Landfill Gas

When investigations of the two landfills began in 1985, OEPA was concerned about potential explosion hazards from methane in the landfill gas. The U.S. Air Force collected only soil gas samples to assess methane migration. As studies continued, OEPA and U.S. Air Force found that hydrogen sulfide and non-methane organic compounds (NMOCs), along with methane, were migrating away from the landfill. Under OEPA's guidance, the U.S. Air Force collected soil gas as well as ambient air and indoor air samples to assess whether landfill gases had migrated to homes.

Soil gas. Permanent soil gas monitoring wells were installed throughout the landfills and near the homes. Analysis of samples from some of these wells found methane at levels well above its lower explosive level (LEL) of 5% by volume and its upper explosive level (UEL) of 15% by volume. Later sampling found NMOCs, such as the gasoline components benzene, toluene, ethylbenzene, and xylenes.

In reviewing these data for its 1990 health consultation, however, ATSDR noted two issues that affect data interpretation:

- *Soil gas monitoring wells filled with water,* in some cases up to 3 feet from the top of the well. Water blocks or reduces gas from entering the well, so that gases found in the well may represent the gases in the soil only a few feet underground. The only two wells that were dry when they were sampled had much higher concentrations of methane (62% and 38% by volume) than wells with water (up to 10% by volume). The two dry wells, therefore, might be most representative of subsurface conditions.
- *The geology of the area might affect gas movement.* Underground channels of sand and gravel are present between layers of clay and silt. The sand and gravel offer the least resistance to gas movement and would create preferred pathways for gas migration. Soil gas wells placed in a sand or gravel channel might have higher concentrations of gases—and represent a worst-case scenario—than wells placed in clay or silt layers. The two wells that were dry when sampled and contained the highest methane concentrations also were placed in sand and gravel.

Ambient air. A series of ambient air samples was collected from locations upwind and downwind of the landfills over a 6-month period from July to December. This sampling effort detected methane, hydrogen sulfide, a number of NMOCs, and several metals. Table D-1 (page D-5) shows the levels of contaminants found during this sampling effort, along with their screening values derived from ATSDR's minimal risk levels (MRLs) (discussed in Chapter Three).

When ATSDR reviewed these data, several factors to consider were identified:

- *Data were collected from July through December.* Sampling over the changing seasons, in this case summer, fall, and winter, provides information about how landfill gas emissions may change throughout the year and react to climatic conditions. No spring sampling data, however, are available. In addition, sampling was conducted in a single calendar year, so that possible changes over the years cannot be assessed.
- *Ambient air was collected as a grab sample.* This presents a snapshot of the gases in air at a single moment in time. Any possible daily changes cannot be assessed, however.
- *The upwind sample contained the highest concentration of some contaminants.* This indicates that perhaps other sources are contributing to ambient air contamination. Identification of non-landfill sources or air modeling of area-wide sources and gas dis-

persion to examine the relative input of various sources to ambient air contamination would prove useful.

Indoor air. Most indoor air sampling done by the U.S. Air Force focused on methane because of concerns about explosion hazards. Low levels of methane were found in homes, but never at levels considered explosive. The U.S. Air Force also conducted one round of indoor air sampling for contaminants other than methane during investigations of the landfills. This sampling revealed only very low levels of hydrogen sulfide and three NMOCs (acetone, toluene, and xylenes), as shown in Table D-2 (page D-6).

Again, data review identified some issues of note:

- *The U.S. Air Force sampled for contaminants other than methane only once.* Sampling for a contaminant only once provides a picture of indoor air contamination for only that point in time. No information is available to assess possible daily, season, or annual changes.
- *The location of indoor air samples was not identified.* Gases may collect in different concentrations throughout a home. For example, methane leaking into a home along plumbing pipes may collect under a sink or in a utility closet. Thus, samples collected in the center of a room do not represent enclosed spaces within the room.

Landfill Gas Safety and Health Issues

ATSDR made a determination, based on available sampling data, that potential explosion hazards, odors, and low-level exposures in homes near the landfill should be evaluated during the 1990 health consultation and the 1999 public health assessment.

Explosion hazard. Indoor air sampling found no explosive levels of methane; however, the data do not indicate if samples were collected in locations where methane might collect to the greatest extent, such as under sinks or in utility closets. Soil gas samples found methane concentrations as high as 62% by volume, well above methane's LEL of 5% as well as its UEL of 15%. Some of the soil gas wells where methane was found above its LEL and/or its UEL were near homes. As methane migrates, concentrations may disperse, so that by the time methane in soil gas reaches homes, it could be present between the LEL and UEL, levels at which explosions may occur. Although homes near the landfill were built on slab foundations, settling of the landfill caused the structure of one housing unit to fail. Foundations of other housing units may also be affected by settling. At a landfill in California, ATSDR had found explosive levels of methane in homes with cracked slab foundations.

For these reasons, ATSDR concluded in its 1990 health consultation that the landfill posed an explosion hazards for housing units built abutting the landfill. ATSDR recommended evacuating homes where explosion hazards existed until landfill gas emissions, especially methane, were controlled. The U.S. Air Force concurred and installed a landfill gas collection system, which was in operation at the time of the 1999 public health assessment.

Odors. Residents living in the housing units near the landfills reported smelling hydrogen sulfide odors. When indoor air in homes was sampled in 1991, hydrogen sulfide was found at levels (0.7 parts per billion [ppb]) just at the odor threshold. Humans begin to smell hydrogen sulfide at levels between 0.5 and 1 ppb. Ambient air monitoring from July through December also found hydrogen at slightly higher levels (to 1.3 ppb). ATSDR has not drawn any conclusions about possible health effects from these odors.

Low-level exposures. Soil gas, ambient air, and indoor air sampling indicate that NMOCs, such as acetone, benzene, toluene, ethylbenzene, and xylenes, were also migrating from the landfills into the surrounding housing areas. In its 1999 public health assessment, ATSDR evaluated ambient air data and found that past exposures to NMOCs were unlikely to cause illness of area residents based on the detected concentrations, the frequency and duration of exposure, and toxicity information. Only past exposures were evaluated, because landfill gas control measures were in operation at the time of the 1999 public health assessment.

Landfill Gas Control Measures

To address concerns about landfill gas migration and exposures to the community living in nearby housing, the U.S. Air Force, under supervision of EPA and OEPA, designed and constructed landfill gas collection systems. Construction of these systems began in 1994 and was completed in 1996. Construction of the collection systems included installing a new landfill cap made of an impermeable geomembrane and a 2-foot soil cover. In order to accommodate the new cap footprint, several housing units abutting the landfills were demolished. The U.S. Air Force collects landfill gas through a series of active gas collection wells and burns the gas in flares. Regular monitoring and sampling of the collection system is required to make sure the system is operating properly.

Community Involvement

The extent of community involvement actions conducted when investigations first began at the landfills is unclear. The details of an ongoing community relations program also are unknown. However, local residents were, and continue to be, invited to attend Environmental Advisory Board (EAB) meetings. The EAB is a group of community members, regulatory agency representatives, and U.S. Air Force personnel that regularly meet to discuss environmental issues, clean-up actions, and community concerns at Wright-Patterson Air Force Base. Meetings are announced in the local papers, and all interested people are invited to attend.

In 1998, the U.S. Air Force conducted a community fair to educate residents living near the landfills about the landfills and proposed future uses of the area, as well as to answer questions and address concerns. This fair was held on a fall evening near the landfills. Posters described the landfills and the actions taken to control landfill gases. People were given fact sheets and telephone numbers to call if they had questions later.

ATSDR attended this fair, as well as an EAB meeting, during the public health assessment process to understand community concerns about the landfills. People expressed concerns about illnesses, specifically cancer and multiple sclerosis, related to exposure to contaminants from the landfills. In its public health assessment, ATSDR addressed these concerns and concluded that past low-levels exposure to landfill gases would not cause illness. The U.S. Air Force has installed a landfill gas control system to prevent any additional exposures.

Table D-1: Summary of Ambient Air Data

	Ambient Air			Screening Values	
Chemical	**Minimum Detected (µg/m^3)**	**Maximum Detected (µg/m^3)**	**Frequency of Detection[a]**	**Value (µg/m^3)**	**Source[b]**
Acetone	45N	236,000NJ	17/40	30,892	EMEG child
Benzene	16.6NJ	17.6NJ	3/40	0.1	CREG
Dimethyl Sulfide	2.9J	5.1J	4/40	not available	
Methylene Chloride	17J	46	5/40	3	CREG
Tetrachloroethylene[c]		16.3J	1/5	0.6	CREG
1,1,2-Trichloroethane		53.6NJ	1/40	0.6	CREG
Trichloroethylene	13N	20.5J	3/40	0.6	CREG
Phenanthrene[d]	0.004NJ	0.02N	37/40	not available	
Arsenic	0.0012J	0.0028J	29/40	0.0002	CREG
Beryllium	0.0006	0.0008	6/40	0.0004	CREG
Chromium		0.0061	1/40	0.00008	CREG
Lead[d]	0.0124	0.0202	16/40	1.5	NAAQS

Source: Engineering Science, Inc. 1993

Notes:

CREG	Cancer Risk Evaluation Guide
child	standard for a child
EMEG	Environmental Media Evaluation Guide
J	data qualifier, indicates that the reported concentration is estimated
N	data qualifier, indicates that the analyte was tentatively identified
NAAQS	National Ambient Air Quality Standards
µg/m^3	micrograms per cubic meter

[a] Frequency of detection is the times detected/times sought.

[b] The EMEGs and CREGs presented are derived using ATSDR's MRLs. The NAAQS are developed by EPA.

[c] Tetrachloroethylene was detected only in an upwind (background) sample.

[d] Phenanthrene and lead were detected below the upwind (background) concentrations (0.033NJ and 0.0205, respectively) at all sampling locations.

Table D-2: Summary of Ambient Air Data

Chemical	Minimum Detected (μg/m^3)	Maximum Detected (μg/m^3)	Frequency of Detection[a]
Methane	2112J	29700J	12/12
Hydrogen Sulfide	1	1	4/12
Acetone	38	3,332J	4/12
Toluene	9.43J	15.46J	3/12
Xylene (total)	8.7J	16.53J	3/12

Source: Engineering Science, Inc. 1993

Notes:		
	J	Indicates that the analyte was detected, but the concentration was estimated
	μg/m3	micrograms per cubic meter

[a] Frequency of detection is the times detected/times sought. Field duplicates are included.

References

ATSDR. 1991. Agency for Toxic Substances and Disease Registry. Health Consultation: Methane Migration at Landfills 8 and 10, Wright-Patterson Air Force Base, Dayton, Ohio. Atlanta: U.S. Department of Health and Human Services. September 12, 1990.

ATSDR. 1999. Agency for Toxic Substances and Disease Registry. Public Health Assessment for Wright-Patterson Air Force Base, Fairborn, Greene County, Ohio. Atlanta: U.S. Department of Health and Human Services. November 12, 1999.

Engineering Science, Inc. 1993. Off-Source Remedial Investigation Report for Landfills 8 and 10 at Wright-Patterson Air Force Base, Ohio. (Revision No. 2). August 12, 1993.

APPENDIX

E Examples

- ATSDR. Landfill Gas—Fact Sheet
- Connecticut Department of Public Health. Fact Sheet: Municipal Waste Landfill Gases
- Missouri Department of Natural Resources. Landfill Gas Facts
- Connecticut Departments of Public Health and Environmental Protection, the Danbury and Bethel Health Departments, and the Bethel Citizens Coalition. Danbury Landfill Update
- Connecticut Department of Public Health. Fact Sheet: Reproductive Health and the Danbury Landfill
- Connecticut Department of Public Health. Draft Response Plan for Elevated H_2S Levels
- Missouri Department of Natural Resources. Design and Construction of Landfill Gas Monitoring Wells
- Missouri Department of Natural Resources. Procedures for Sampling Landfill Gas Inside Buildings
- Missouri Department of Natural Resources. Sampling of Landfill Gas Monitoring Wells

Landfill Gas—Fact Sheet

Municipal solid waste (MSW) landfills emit gas that may reach surrounding neighborhoods. This fact sheet contains general information about the sources of landfill gas, where it goes, and the possible health and safety concerns that may be associated with it.

Where does landfill gas come from?

Bacterial activity causes the wastes in landfills to decompose over time. As these wastes decompose, gas is produced. The amount of gas created varies and depends on factors such as: the amount and type of waste; moisture content of the landfill; amount of oxygen present; landfill size and characteristics; and temperature. Also, certain chemical reactions and the evaporation of some chemicals produce landfill gas.

Most landfill gas is created within a few years after waste is dumped, when the rate of decomposition is highest. Almost all gas is produced within 20 years after waste is dumped.

Where does landfill gas go?

Gas is created under the landfill surface and generally moves away from the landfill, either by rising up through the landfill surface or migrating underground to surrounding areas.
Three factors influence where gas goes:

(1) Permeability. Gas flows through areas of least resistance. If one side of the landfill is very permeable, then gas will likely leave the landfill from that area. Artificial channels such as drains and trenches can act as pipelines for gas movement.

(2) Diffusion. Gas moves to areas with lower gas concentrations. Gas concentrations are generally lower in areas surrounding the landfill.

(3) Pressure. Gas moves to areas of lower pressure. This means that the pressure of the surrounding areas (e.g., changing weather conditions) will affect gas movement from the landfill.

Gas that is released into the air is carried by wind. While wind dilutes the gas with fresh air, it can also move gas into neighboring communities. Wind speed and direction determine how much gas reaches nearby residents, so the degree of the problem varies greatly from day to day. At locations near the landfill, the worst time of the day is often early morning because winds tend to be gentle, providing the least dilution of the gas.

What types of gas are produced?

Landfill gas is typically about 50% methane and 50% carbon dioxide, and less than 1% sulfides (e.g., hydrogen sulfide, dimethyl sulfide, mercaptans) and non-methane organic compounds (NMOCs) (e.g., trichloroethylene, benzene, and vinyl chloride). The amount of sulfides and NMOCs varies from landfill to landfill and depends on whether the landfill receives wastes containing these chemicals and whether chemical reactions are occurring which create or remove them.

What causes the odor?

Sulfides are the source of the "rotting" smell often noticed near landfills and can cause this unpleasant odor even at very low concentrations. Some NMOCs also have recognizable odors. Methane and carbon dioxide are odorless. Odors can be destroyed by collecting and flaring the landfill gas or by venting it through special filters. Also, certain chemicals can be used to mask landfill gas odors.

In addition to landfill gas, there are three other common sources of landfill odor:

- New waste being dumped
- Special wastes with strong odors such as manures and fermented grains
- Leachate (liquid within the landfill) coming to the surface

Odors from the dumping of new and special wastes do not tend to last long and are usually not noticeable beyond a few hundred feet of the dump site.

> ***Note:*** Although certain types of gas cause odors, odor is not a good indicator of whether gas is present in surrounding areas because: (1) many gases do not have strong or distinctive odors, and (2) people get used to odors quickly so that they stop noticing them. Periodic monitoring is necessary to determine the nature and extent of landfill gas emissions.

What health and safety hazards are associated with landfill gas?

Health Concerns. Landfill gas generally represents more of an odor nuisance than a community health hazard; however, there are some potential health concerns you should be aware of:
Some people may experience slight nausea or headache when they smell a bad odor. Although this is highly undesirable, the effects usually reverse when the odor goes away and do not require medical attention.

There is some concern that hydrogen sulfide might precipitate asthmatic attacks in highly sensitive people. However, a controlled study of asthmatics found that exposure to levels of hydrogen sulfide higher than those found at most landfills did not trigger an asthmatic attack or alter respiratory function.

Certain NMOCs are known carcinogens (e.g., vinyl chloride, benzene, and chloroform), and some NMOCs may have adverse effects on organ systems such as the kidney, liver, pulmonary, reproductive, and central nervous systems. However, the levels of NMOCs likely to reach surrounding communities are far below levels known to cause any ill effects. In most cases, landfills do not emit enough NMOCs to increase their concentration above the background levels commonly found in the community. Current research efforts are looking into the potential cumulative effects of being exposed to low levels of the types of NMOCs emitted from landfills.

Methane Gas Explosions. The accumulation of methane gas in structures both within and beyond the landfill (e.g., basements, crawl spaces, utility ducts) has resulted in explosions and fires which have caused personal injury and death. Accumulation is often the result of underground gas migration. EPA regulations require large landfills to monitor and control methane emissions.

How Can Explosion Risks and Odors be Reduced?

Passive vents and active gas pumping systems can be used to control the migration of methane gas. Passive systems use natural pressure gradients and trenches or pipes to vent landfill gas to the atmosphere. These vents can be equipped with flares to burn off gas (Note: this control can also be used to destroy odorous gases). If there is a high risk of methane accumulating in nearby structures, active gas collection systems are used to literally pump gas out of the landfill and recover it. A growing trend at landfills across the country is to use the recovered methane gas as an energy source. Collecting methane gas for energy use greatly reduces the risk of explosions, provides financial benefits for the community, and conserves other energy resources.

Connecticut Department of Public Health

** * * * FACT SHEET * * * **

MUNICIPAL WASTE LANDFILL GASES

Introduction: Where Do Landfill Gases Come From?

Gases released from municipal waste landfills have the potential to cause odors in neighborhoods surrounding the landfill. The household and commercial wastes brought to landfills decompose over time largely through the action of bacteria. This process produces odorous gases, the amount formed depends upon a variety of factors: nature and moisture content of the waste, amount of oxygen present, and temperature inside the landfill. Less odorous gases can also be generated at landfills due to chemical reactions and due to the evaporation of chemicals put into the landfill. Any gases generated tend to rise through the landfill and reach the air above, although the rate at which this occurs is affected by landfill content and by the weather. The amount of gases emitted will vary from landfill to landfill and will be different for a single landfill at different times (e.g., due to changing weather, changing landfill content).

Once emitted into the air, landfill gases are carried on surface level winds. While this dilutes the gases with fresh air, it can also move them into the community. Naturally, wind speed and direction determine whether local residents will notice landfill odors so that the degree of the problem will vary greatly from day to day. At locations near the landfill, the worst time of the day may be early morning. This is when winds tend to be most gentle, providing the least dilution of the gas. Additionally, this early morning effect is usually greatest in fall and spring.

What is Present in Municipal Waste Landfill Gases?

Methane and carbon dioxide are the major gases produced by the bacterial decay of landfill wastes (USEPA, 1991). Methane present underground is flammable, but it is not associated with odors or hazards once emitted into the air above the landfill. Other gases produced by landfill bacteria are termed reduced sulfur gases or sulfides (e.g., hydrogen sulfide, dimethyl sulfide, mercaptans). These odorous gases give the landfill gas mixture its characteristic "rotting" smell.

Other chemicals can also be present in landfill gases, although their levels are typically very small compared to the levels of methane, carbon dioxide, and sulfides (USEPA, 1991; ERL, 1995). Many different volatile organic chemicals (VOCs) have been found in landfill gases with the amounts varying from landfill to landfill depending upon whether the landfill received wastes containing these chemicals. Also, the amounts of VOCs in landfills depends upon whether chemical reactions are occurring which either remove or create them.

What Health Effects Can Landfill Gases Cause in People Living Nearby?

Sulfides can cause unpleasant odors even at very low concentrations. These concentrations are well below the level needed to produce toxicity (Shusterman, 1992).

This means that landfill odors represent more of a public nuisance than a community health hazard, with the odors not being a good indicator of whether other chemicals are present. However, for some people, simply smelling an unpleasant odor can be sufficient to create an adverse physiological response (nausea, headache, etc.). Although this situation is highly undesirable, the effects usually reverse when the odor dissipates and do not require medical attention. While there is some concern that odors might precipitate an asthmatic attack in highly sensitive people, a controlled study of asthmatics found that exposure to a high level of hydrogen sulfide (2 parts per million - ppm) did not trigger an asthmatic attack or alter respiratory function (Jappinen, 1990).

Other VOCs that might be present in landfill gas are less odorous than sulfides, and the levels that might reach surrounding homes are generally far below that which is known to cause ill effects (USEPA, 1991; ERL, 1995; CTDPH, 1996). In most cases landfills do not emit enough of these VOCs to increase their concentration above the background levels commonly found in the community. Gasoline, household products (e.g., glues, paints), and other sources in the community are usually more significant sources of these VOCs than are landfills. While this is typically the case, it should be noted that the amounts of these VOCs can vary from one landfill to the next depending upon what historically was disposed of in the landfill. At Connecticut landfills where odors have been a concern, air sampling has shown VOC levels to be minimal (CTDEPAir Management Bureau Data).

In summary, this is general information and each landfill needs to be considered separately since they differ widely in composition. While landfill gases are not usually a significant public health hazard, the odors may, at times, be unpleasant and produce discomfort and temporary symptoms. Measures to capture landfill gases and prevent their migration to the community are warranted where odors create a persistent nuisance.

Where Can I Get More Information?

You can contact your local health director to find out more about the landfill in your town. The Connecticut Department of Public Health can be called to discuss the health aspects of landfill gases (860-509-7742), while the Connecticut Department of Environmental Protection Bureau of Waste Management (860-424-3366) can be contacted to discuss landfill testing and management.

Key Sources Used to Develop Factsheet

CTDPH (1996) Health Consultation: Hartford Landfill, Review of Air Emissions Data.

Jappinen, P., et al. (1990) Exposure to hydrogen sulfphide and respiratory function. British Journal of Industrial Medicine, pgs 824-828.

USEPA (1991) Air Emissions from Municipal Solid Waste Landfills - Background Information for Proposed Standards and Guidelines. EPA-450/3-90-011a.

Environmental Risk Limited (1995) Evaluation of Air Emissions at the Hartford Landfill. ERL Project No. 4100003346.

Shusterman, D. (1992) Critical review: the health significance of environmental odor pollution. Arch. Env. Health 47: 76-87, 1992.

Missouri Department of Natural Resources

Landfill Gas Facts

What is Landfill Gas?

Landfill gas is generated during the decomposition of trash. The major gases generated in a landfill are methane and carbon dioxide. Nitrogen is produced, initially at high levels, then drops rapidly until it stabilizes at low levels.

Additional gases, called trace gases, are produced in much smaller amounts. Hydrogen sulfide is a trace gas that gives landfill gas its characteristic odor. Other trace gases may also be produced, depending on the composition of the waste.

Does Landfill Gas Pose an Immediate Threat?

Methane gas is the constituent of concern in landfill gas. It is a by-product of landfill decomposition and is colorless and odorless. Methane is highly explosive at certain concentrations in air (between 5% and 15% of the total air volume). Methane can become dangerous when it migrates into confined spaces in these concentrations. Confined spaces can range from trenches or holes in the soil to buildings and structures. Additionally, higher concentrations of methane in confined spaces can displace the oxygen and may lead to suffocation.

How Do I Protect Myself From Methane Gas?

An individual can take a number of steps in order to minimize the risk associated with gases migrating from a landfill.

Step 1: Properly ventilate all confined spaces. Some examples are removing some of the skirting from around a mobile home or opening basement and garage windows.

Step 2: Remove all potential ignition sources (portable heaters, open flames, etc.) in confined spaces which cannot be properly ventilated.

Step 3: Install a methane gas detector with an alarm set at or close to 1% methane gas by volume [20% of the Lower Explosive Limit (LEL)] in buildings or structures.

Information Sources

For more information contact these agencies:

Missouri Department of Natural Resources
Solid Waste Management Program
P.O. Box 176
Jefferson City, Missouri 65102
Phone: (573) 751-5401

Missouri Department of Natural Resources
Environmental Services Program/
Environmental Emergency Response
P.O. Box 176
Jefferson City, Missouri 65102
Phone: (573) 526-3315
Emergency: (573) 634-2436

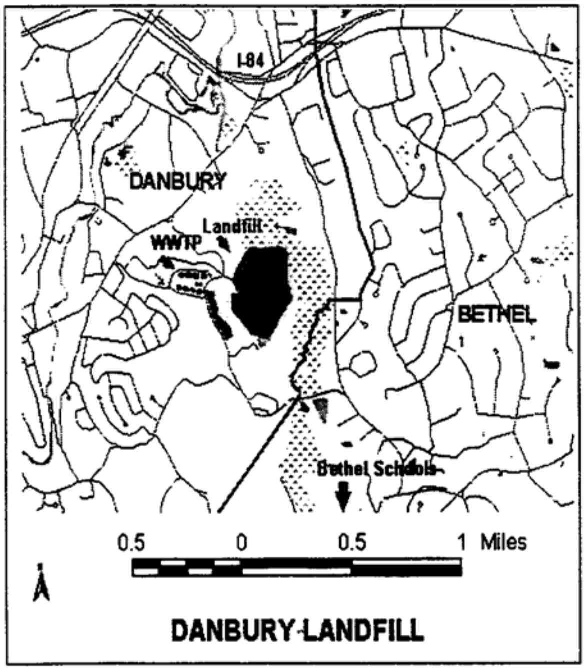
U.S. Environmental Protection Agency
Region VII Office
726 Minnesota Avenue
Kansas City, Kansas 66101
Phone: (913) 236-3884

You can also contact your local fire department or Emergency Planning Commission.

Danbury Landfill Update

February 1997

A Joint Newsletter of the CT Departments of Public Health and Environmental Protection, the Danbury and Bethel Health Departments and the Bethel Citizens Coalition. The articles represent the perspective of the contributing organizations.



Introduction from the Bethel Health Department

Laura Vasile, Bethel Health Director
Charles Steck, Bethel 1st Selectman

Since approximately August 1996, the Town of Bethel has been grappling with a serious odor problem originating from the Danbury landfill. The Bethel areas which appear to be affected the most are Shelter Rock, Payne Road, Castle Hill, Meckauer Circle, Brookview Court, Chimney Heights and the school complex. Some days the odor permeates an even larger portion of the town. We have received hundreds of calls about the situation.

This newsletter has been produced to provide you with information concerning the on-going investigation and activities to eliminate the odor. It is a product of a collective effort involving the Department of Public Health (DPH), the Department of Environmental Protection (DEP), Danbury, Bethel and the newly formed Bethel citizen's coalition. This first issue includes an overview of recent developments and responds to the major health and environmental issues raised by residents.

Bethel Health Department has taken a pro-active stance and has actively sought the participation of the Commissioner of the DEP, the Commissioner of Health, Governor Rowland, our Congressmen, State Representatives and the residents of the Town of Bethel to help resolve the odor problem.

The DEP is charged with the regulatory authority under the State of Connecticut general statutes to regulate landfills for air quality and solid waste issues. The DPH is responsible to assist with public health issues related to the odor. This odor problem is not an environmental health problem directly under the control of either the Bethel Health Department or the Board of Selectmen for the Town of Bethel. Our role has been to coordinate activities with the city of Danbury and the various state agencies to bring this matter to an end. Both municipalities are obviously interested in a solution to this odor problem.

Due to concern for their children's health at home and at school, residents requested a public meeting be held to address the odor. The first public information meeting was held at Bethel High School on December 12, 1996. Residents spoke of short term ill health effects they were experiencing when the odor was present in their homes and on their property. They also voiced concerns about the odor in the school buildings, and asked specific questions of state environmental and health specialists and Danbury officials.

On December 17, 1997, the DEP and DPH came to a Bethel Citizen's meeting at the Bethel Municipal Center to address issues raised by Bethel and Danbury residents at the first public informational meeting. At that time, DEP technical specialists from the Water, Waste and Air Bureaus each took time to set forth a strategy to address residents requests. Groundwater sampling was requested to assure there was no contamination of the water within the vicinity of the landfill. Four wells have been tested and results are pending. Residents took a tour of the Danbury sewage treatment plant and Danbury has offered this to any other interested groups. The DEP has requested that Danbury speed up the process for installation of the gas recovery system at the landfill and requested installation of a temporary system to begin burning off the odor. This system should be in place by April 15, 1997. The DEP committed to conducting representative air sampling data of the odor as it exists in the community. Random samples will be conducted on private properties, in several homes and at the Bethel school complex. Air data is being made available to the public as it becomes available.

Bethel Health Department has been maintaining an odor registry since August, 1996. Many area residents still complain of itchy, watery eyes, scratchy throats, runny noses, headaches, stomach aches and an increase in asthma episodes, inhaler use, sinusitis, ecetera. We are advising everyone with medical concerns to see their primary physician. The primary physician can refer you to a specialists in environmental medicine for further evaluation if necessary.

A third meeting was held on January 29, 1997 at the Bethel Municipal Center to discuss placement of a cap over the landfill and provide an update on the air monitoring sampling strategy. We encourage your active participation in future meetings. If you would like to participate and more actively monitor the odor resolution process we encourage you to contact the Bethel Citizen's Coalition.

Update from the Department of Environmental Protection (DEP)

Background Information

In 1993 the DEP informed Danbury officials that the landfill would require closure in accordance with Federal regulations. A consent order with the City of Danbury issued prior to the odor problem (12/19/95) required the following items:

- Stop receipt of waste by 12/ 31/96;
- Submit design of gas recovery system by 12/19/96;
- Complete the final cover and vegetation by 7/31/97; and
- Complete wetland mitigation and compensation actions by 10/1/97.

Closure Plan Requirements

- Requires the City of Danbury to cover the landfill with 18" of cover soil.
- Cover landfill with a synethic cap over the top 9 and 1/2 acres.
- Cover the entire landfill with an additional six inches of top soil and seeded.
- Install a gas recovery system.

Odor Controls

During November 1996 DEP requested the City of Danbury to expedite the covering of the landfill with 12" of cover soil and to install a temporary gas recovery system before completion of final cover. This system will be operational by April, 1997.

Also during November, the City of Danbury began applying soil onto the landfill to mitigate odors at a rate of 1,000 cubic yards per day. As of January 26, 1997 approximately 77,500 cubic yards of final intermediate cover has been applied to the landfill by the City of Danbury.

In December 1996, DEP approved a request by the City of Danbury to apply lime to the landfill in an attempt to control odors.

On December 19, 1996, DEP received from the City of Danbury plans for the installation of the temporary and permanent gas recovery system. These plans were reviewed on Jan. 3rd with Danbury officials.

At a Jan. 30th meeting Danbury officials submitted a preliminary schedule which will result in eleven gas collection wells and a temporary flare operational by April 30, 1997. The permanent flare which will incorporate a scrubber system to remove sulfur will be operational by August 1, 1997. The DEP is drafting a Consent Order which will incorporate the above schedule and other interim dates regarding installation of the gas recovery system.

On February 3, 1997, the DEP issued an "Authorization for Disruption" which authorizes the City to perform the final grading of the landfill in preparation for the installation of the gas recovery system and flare, and the final landfill capping.

Water Sampling Activities

On Jan. 30, 1997, staff from the DEP and the Bethel Health Director conducted sampling of four homes, one of which is supplied by a system that services multiple homes. Target analytes are volatile organic compounds, metals and leachate parameters. Samples were split between the State Health Department Lab and a private lab selected by Bethel Citizens Coalition. DEP will review the analysis with the Bethel Health Director.

Groundwater Monitoring Wells Adjacent to the Landfill

Groundwater wells are monitored on a quarterly basis by a Danbury consulting firm. At the request of the Bethel Citizens Coalition, during the next sampling event by Danbury's consultants, DEP will conduct split sampling analysis on selected groundwater monitoring wells at the landfill.

Leachate Collection System

Leachate is rainwater which passes thru the landfill and reaches groundwater if not collected. DEP has reviewed design of the leachate collection system and provided comments to the City of Danbury. DEP is awaiting response to those comments. The City has been made aware of the general permit process requirements.

Sewage Treatment Plant Tour

On December 20, 1996 the DEP conducted a two hour Danbury Sewage Treatment Plant tour with representatives from the Bethel Citizens Coalition, EPA Officials, Sewage Treatment Operators, Danbury Officials, and the Bethel Health Director. The tour consisted of a review of the sewage treatment plant operations including sludge process, odor controls, and computerization of the plant processes.

The Danbury Plant utilizes enclosed digesters to process sludge. Gases produced by this process are destroyed prior to being released to the air. Under certain weather conditions a water vapor cloud can be formed by the trickling filters. This cloud has not been identified as a source of odor.

Air Sampling Activities

DEP has been conducting field surveys using its recently acquired hydrogen sulfide sampling equipment. Initial efforts included determining the operational capabilities of the equipment and establishing sampling procedures.

The equipment has been utilized to provide round-the-clock, multi-day sampling of the air at a private residence near the landfill in Bethel. This sampling included a period with strong odors. Results to date have shown that levels are below the World Health Organization community air guideline, but above nuisance odor levels.

The hydrogen sulfide sampling program will be continued and expanded by DEP in coordination with the Bethel Citizens Coalition. Various locations and conditions will be sampled on a 24 hour, multi-day basis to provide information to the state Health Department for their evaluation. In addition, DEP is preparing to conduct sampling for other volatile compounds which may be in the landfill gas.

Dept of Public Health Activities

The CT Department of Public Health, Division of Environmental Epidemiology and Occupational Health (EEOH) first became involved with the Danbury Landfill last fall at the request of the Danbury and Bethel Health Departments. Local health departments are the primary vehicle for resolving community odor or health complaints. The state health department becomes involved when additional expertise, information or general support are needed. We at EEOH recognize the problem the landfill has become for the community, especially for Bethel residents living nearest to the landfill and for the Bethel schools. The complaints received by the Bethel Health Director make it obvious that the odor is having an impact on the quality of life in these neighborhoods. Hydrogen sulfide is the major odorant gas released at the landfill.

One of the first efforts undertaken by EEOH was to map the complaints received by the Bethel Health Director. This information has been useful in focusing air monitoring now underway by DEP. EEOH has reviewed the air monitoring data collected to date, which includes data taken from the landfill proper, from the neighborhoods surrounding the landfill, and from the Bethel High School. The sampling results have been consistent in showing low or non-detectable hydrogen sulfide levels in the community. This takes into consideration DEP's recent sampling (1/31-2/4) from the yard of a Bethel resident near the landfill during a period with strong odors. DPH will continue reviewing sampling data as it is collected by DEP or other parties.

EEOH has reviewed the scientific literature related to hydrogen sulfide and landfill gases. The landfill gases fact sheet developed by EEOH summarized our review. This fact sheet has been widely distributed to residents of Bethel and Danbury. The major point is that the strong sulfur odor experienced in parts of Danbury and Bethel occurs at very low hydrogen sulfide levels. The odors, on their own, can be unpleasant and make people sick (e.g., nausea, headache). However, much higher levels than those so far found in Danbury or Bethel are required to cause toxic effects (irritant damage to eyes or respiratory tract). Hydrogen sulfide is not known to cause chronic effects such as cancer, and does not pose a risk to pregnant women or their offspring.

Sampling data so far collected suggests that other chemicals which might be present at landfills are not a concern in the air coming from the Danbury landfill. EEOH is working with DEP in developing an air sampling program that will better characterize community levels of hydrogen sulfide and other landfill-related chemicals.

As part of our role in assessing public health, we have contacted area physicians to find out if they have patients who feel the landfill may have affected their health.

Area Physicians Discuss Danbury Landfill

Dr. Edward Volpintesta
Chair, Primary Care Roundtable

Our January 30th Primary Care Roundtable at Danbury Hospital focused upon odor and health issues associated with the Danbury Landfill. Presentations were made by Dr. Mary Lou Fleissner of the Connecticut Dept. of Public Health and by Dr. Michael Hodgson who is in Environmental and Occupational Medicine at the University of Connecticut. Approximately 25 of our area physicians attended; also in attendance was Representative James Maloney. Everyone agrees that the odor has created a major nuisance which at times might prompt symptoms in certain patients. However, the physicians were reassured that long-term health problems are unlikely given the large margin of safety between the levels so far measured in the community and the much higher levels of hydrogen sulfide required to cause toxic effects.

This meeting increased understanding of the issues, enabling physicians to better address the concerns of their patients. Working with patients whose health may be affected by the odors is important during this period where landfill odors still occur. Area physicians can consider patient referrals to occupational and enviromental medicine specialists.

Bethel Citizens Coalition

Joanne Kirk

The Bethel Citizens Coalition (BCC) consists of Bethel residents (and nearby Danbury residents) who have been adversely affected by the unrelenting emissions of hydrogen sulfide gases from the Danbury Landfill. BCC began to evolve as residents aggressively pursued local and state officials in search of answers. As residents made phone calls, wrote letters, sought out other vocal residents and shared information, the coalition began to solidify.

BCC is working with local and state officials in moving this environmental crisis toward a speedy and complete resolution. BCC's primary focus is to ensure that the capping and installation of the gas recovery system will be properly designed, executed and will operate effectively, thus affording the affected community with the highest level of safety and finality. To elaborate, the final cap (originally proposed to only cover the top ten acres) is intended to 1) minimize infiltration of precipitation into the landfill, 2) reduce erosion and infiltration of oxygen which can affect the gas collection wells, 3) minimize leachate generation, and 4) reduce the impacts of the landfill on groundwater quality. In consideration of the severity of the odor problem, BCC is primarily concerned with *complete closure*. It has been determined that a synthetic cap over the entire landfill will offer the additional level of protection needed and offset the likelihood of re-occurrence.

Moreover, the BCC is committed to obtaining further comprehensive air and water testing in response to residents' existing, short term health effects and any potential long term health effects. Other issues BCC continues to address include, but are not limited to, health and safety plans for well excavations and testing of excavated materials, capping and gas collection design and review, CTDEP permitting process (including materials), restoration of surrounding wetlands, establishment and publication of capping and installation timetable, property values, current market conditions and legal recourse.

In addition to other informational vehicles provided by local and state officials, BCC has initiated and organized two public informational meetings. These forums were held on October 10, 1996 at the Shelter Rock Elementary School in Danbury and December 12, 1996 at the Bethel High School and were attended by Bethel and Danbury residents, officials, CT DEP, health officials and engineering consultants. BCC encourages the media to provide coverage of these and other related events as a means of disseminating clear and accurate information to the public.

Landfill Update from Danbury

The City of Danbury has accelerated the pace of closure of the Landfill. The Landfill was closed for waste disposal on December 31, 1996. Since November, the City has been working to install a final layer of impermeable soils over the entire landfill. The City is using private contractors in addition to City crews to deliver the final cover. The application of final cover will reduce water infiltration and should lower the production of leachate, which is one of the sources of odors. Additionally, a layer of lime is being applied to the surface of the landfill in an attempt to neutralize the production of odor producing gases.

On December 19, 1996, the City submitted its final design of the gas collection system to the DEP for approval. DEP is actively reviewing this design. The gas collection and recovery system is considered to be the ultimate solution to the odor problem. The permanent gas collection and recovery system will be operational by summer.

Additionally, the City has applied to DEP to install a temporary flare, which, if approved, could be installed by early spring. Although a temporary flare will not be as effective as the permanent system, it should have a substantial effect in reducing the odors as a temporary measure while the permanent system is being installed.

Air monitoring at the landfill and in the communities around the site is continuing. Periodic measurements taken at 21 commercial and residential locations consistently show that hydrogen sulfide levels are less than 0.1 parts per million. This level is the instrument's lowest detection limit. The City will continue this monitoring program until the gas collection system is shown to be fully effective.

For More Information:

Bethel Health Department
Laura Vasile, Director
(203) 794-8539
Danbury Health Department
William Campbell, Director
(203) 797-4625
Bethel Citizen's Coalition
Joanne Kirk
(203) 748-0324
CT DEP
Dick Barlow, Chief
Bureau of Waste Management
(860) 424-3021
Carmine DiBattista, Chief
Bureau of Air Management
(860) 424-3026
CT Department of Public Health
Mary Lou Fleissner,Dr.P.H.,Director EEOH
Gary Ginsberg, Ph.D., EEOH
(860) 509-7742

Connecticut Department of Public Health
** FACT SHEET -- January, 1997 ******

REPRODUCTIVE HEALTH AND THE DANBURY LANDFILL

Introduction

Health concerns have been raised by residents in the town of Bethel due to their exposure to odors stemming from the Danbury Landfill. Odors from the landfill have increased since August, but this situation should be improved when a gas collection system and flare are installed (expected in spring, 1997). One of the health concerns expressed by community residents is that pregnant women or their offspring may be affected by the gases emanating from the landfill. The following sections summarize what is known about these gases and their implications for risk during pregnancy.

What is in the gases Coming from the Danbury Landfill?

Most of the gas emitted from typical municipal waste landfills consists of methane and carbon dioxide. These gases are non-odorous and not toxic at concentrations that can be reached in community air. Odorous gases that can come from landfills are hydrogen sulfide and other reduced sulfur gases. The air monitoring data thus far available at the Danbury Landfill suggests that hydrogen sulfide is the major cause of odor in the communities around the landfill. A variety of different volatile organic chemicals (VOCs) can also be released from municipal waste landfills, but these levels are usually quite low. The limited sampling data from Danbury supports the concept that VOC emissions from the landfill are too low to present a public health threat. Follow-up air sampling is being planned by state and local officials in conjunction with citizens.

Is Exposure to Hydrogen Sulfide a Risk Factor During Pregnancy?

Given that hydrogen sulfide seems to be causing strong odors around the landfill, it is relevant to consider whether exposure to this gas could be a risk during pregnancy. This possibility has been addressed in laboratory animal studies involving daily exposure during pregnancy to hydrogen sulfide at relatively high concentrations (up to 150 ppm; for comparison the highest level measured in the neighborhood around the landfill to date is 0.015 ppm). In these studies, hydrogen sulfide did not cause birth defects, pregancy loss, or decrease in birthweight. This evidence has led the US Environmental Protection Agency (EPA) to conclude that hydrogen sulfide does not appear to alter fetal development.

Although human exposures occur to hydrogen sulfide in occupational settings and in communities surrounding landfills, there has been very little evaluation of reproductive outcomes in these populations. The few studies that have been conducted have had too many limitations to be useful. Therefore, the animal studies form the basis for evaluating reproductive risks associated with hydrogen sulfide.

Is the Danbury Landfill a Risk to Pregnant Women?

The air sampling data thus far collected suggest that the levels of hydrogen sulfide in the community are low, and in fact, far below the levels tested in the animal studies. Additional sampling is being planned to provide more detailed air quality data around the landfill. While the sulfide gases coming from the landfill are unlikely to affect reproduction, the levels are high enough to produce strong odors. These odors may be highly unpleasant and at times, may be sufficient to make people feel ill. It should be kept in mind that such illness is a reaction to the odor and should improve once the odor dissipates.

The only criterion for hydrogen sulfide levels in the community is the World Health Organization (WHO) level of 0.11 ppm. This level is meant to protect the general public from any toxic effects (including reproductive effects) from hydrogen sulfide, although it is recognized that odors will be unpleasant at this level. Air testing conducted thus far in the community around the Danbury Landfill have found levels well below the WHO criterion.

In summary, the Danbury landfill is unlikely to be a reproductive risk to pregnant women in the surrounding community for the following reasons:

- Hydrogen sulfide is not considered to be a significant reproductive risk factor;
- The levels of hydrogen sulfide in the community appear to be low;
- Testing for other landfill gases have found that VOCs were either not present or at levels too low to be a public health risk.

If you would like additional information, contact the State Department of Public Health at 860-509-7742, your health care provider, or the Pregnancy Risk Hotline (1-800-325-5391).

DRAFT

RESPONSE PLAN FOR ELEVATED H2S LEVELS

The response tiers established below would be triggered by readings on the Jerome H2S analyzer that surpass the indicated concentration for the specified length of time in areas where human exposure to these concentrations is likely (e.g., residential/retail areas). The indicated response would only occur if these levels are likely to continue for at least one additional hour based upon the time-frame for mitigative measures. Tiers 2 and 3 involve public alerts that advise the public in the area to alter their behavior, on a voluntary basis, to avoid landfill-related odors. While a GasTech analyzer will also be in use for H2S monitoring, this is a screening type device and will be confirmed with the Jerome analyzer before response actions are initiated.

Tier 1 H2S Level: ≥ 0.1 ppm for 2 hours or 0.5 ppm for 15 minutes
(up toTier 2 levels)

Tier 1 Response: The Danbury Health Director alters the telephone message for medical/emergency response personnel to indicate that H2S concentrations in the community, while below a toxic effects level, are elevated to a range where strong odors may affect sensitive individuals (e.g., transient nausea, headache). In addition, it would be noted that strong odors of any kind may prompt increased symptoms in some asthmatics.

Tier 2 H2S Level: ≥ 0.5 ppm average for 2 hours or 2 ppm for 15 minutes
(up to Tier 3 levels)

Tier 2 Response: The Local Health Directors will alert the public in the exceedance area (areas delineated by monitoring that have the exceedance) that sensitive individuals (e.g., asthmatics, young children) stay indoors and cease performing work or physical exercise; alternatively, such individuals may want to temporarily leave the area surrounding the landfill where the odors are strongest. If the exceedance area includes the Bethel school complex, and if it occurs during school hours, the Local Health Director will notify school officials. The Danbury Health Director will also change the phone message for medical personnel to indicate an increase in H2S to a level that, while below a toxic effect level for the general public, may possibly produce reversible effects in sensitive individuals (increased airway resistance, irritation).

Tier 3 H2S Level: ≥ 5 ppm average for 30 minutes

Tier 3 Response: The Local Health Directors will alert the public in the exceedance area (areas delineated by monitoring that have the exceedance) that all individuals may consider temporarily leaving the area. The Danbury Health Director will also change the phone message for medical personnel to indicate that H2S concentrations are in a range where reversible irritative and biochemical effects are possible in exposed individuals.

Notes: For Tiers 1 thru 3 the Local Health Directors will notify all parties that the exceedance has ended once verification of this has been obtained. The exact trigger points for these tiers may shift if it is found that the community has a more pronounced response to a given H2S concentration than what is expected based upon the literature.

SUPPORTING INFORMATION

DPH has reviewed the H2S toxicology and epidemiology literature, as well as H2S exposure guidelines developed by other states, by the World Health Organization, and by OSHA/NIOSH. DPH's assessment factored in the animal and human H2S database but relies more heavily upon the human studies (occupational studies, controlled exposure chamber studies, epidemiology studies) than upon animal studies. The available evidence suggests that H2S effects begin to occur at concentrations as low as 5 ppm in healthy subjects (irritation, elevated blood lactate levels) and as low as 2 ppm in asthmatics (increased airway resistance and decreased conductance in 2 of 10 subjects). NIOSH has a workplace ceiling of 10 ppm meaning that workers should not be exposed to this level for more than occacional, brief periods.

To our knowledge, the only state that has produced a risk assessment addressing emergency response actions is Hawaii. Based upon the human data, the Hawaii Health Environmental Management Division recommended three tiers: 0.1 ppm as a public alert level; 1 ppm as a public warning level; 10 ppm as a public emergency level. Based upon the H2S animal toxicology literature, their recommendations were approximately 10 fold more conservative (lower H2S levels needed to trigger action). The state of Nebraska just completed a risk assessment to establish an H2S health-based (as opposed to odor-based) ambient standard. Their assessment developed a standard of 0.1 ppm as a 30 minute average, above which the source must be controlled (this proposed standard has recently been released for public review). The World Health Organization developed an ambient guideline for Europe of 0.1 ppm H2S (24 hour average concentration) based upon ocular irritation effects and a 100 fold safety factor. Additionally, ATSDR's draft Toxicological Profile for Hydrogen Sulfide is supportive of limiting exposures to the general public in the concentration ranges outlined in DPH's 3 tiers.

Review of these data sources suggests that an average H2S concentration of 0.5 ppm for 2 hours or a 15 minute peak of 2 ppm would be sufficient to put sensitive subjects at risk for health effects. The first level of public notification (Tier 2) is intended to avoid these risks. The 2nd level of public notification (Tier 3) is intended to also avoid health effects in the general population which may begin as low as 5 ppm. Tier 1 would be established to notify medical and emergency response personnel that H2S concentrations are elevated into a range where certain members of the community may be in distress (due to strong odors) and may report with readily reversible symptoms.

MISSOURI DEPARTMENT OF
NATURAL RESOURCES

Design and Construction of Landfill Gas Monitoring Wells

Technical Bulletin
10/1999

Division of Environmental Quality
Solid Waste Management Program

Overview

This document was prepared by the Missouri Department of Natural Resources' Solid Waste Management Program (SWMP) to provide guidance for the proper design and construction of gas monitoring wells to comply with the quarterly monitoring required by 10 CSR 80-3.010(14) and 10 CSR 80-4.010(14).

Well Designs

Proper design and construction of gas monitoring wells is critical in obtaining true soil gas concentrations. All wells should be designed to minimize air intrusion into the system so accurate soil gas samples can be collected. All monitoring wells that are deeper than 10 feet are regulated by the department's Division of Geology and Land Survey (DGLS) and must be installed by a certified well driller. For further information on this subject, call (573) 368-2100. The SWMP recommends the following well designs:

- Code Well - This design meets current well drilling codes required by 10 CSR 23-4. Refer to figure 1, which illustrates major components.

- Micro Well - This design is not permitted under current well drilling codes but permission to install this type of well can be obtained through the department's Division of Geology and Land Survey. Refer to figure 2, which illustrates major components.

- Spike Probe - This is not actually a monitoring well by definition since its use is confined to amaximum of 10 feet below ground surface. For this reason no variance is required from DGLS. Refer to figure 3, which illustrates major components.

Well Selection and Location

The location of gas monitoring wells should be based on a characterization of geologic and hydrologic conditions at the landfill site and on the adjacent land uses, which must be approved by the Solid Waste Management Program.

This technical bulletin discusses factors that should be considered before selecting a certain type of well for installation.

For landfills applying for a disposal area permit, and existing landfills with gas migration problems, in-ground monitoring for gas migration must be performed using gas monitoring wells. Spike probes may be used where shallow groundwater, approximately 10 feet or less below the surface, prevents construction of a drilled well. The SWMP does not consider bar punch testing for shallow soil migration to be an effective monitoring method for other than instantaneous monitoring to evaluate the extent of shallow lateral gas migration.

Subsurface monitoring for methane should be conducted around the perimeter of the disposal area. The point of compliance for regulatory limits of methane migration is at the landfill property boundary. However, at sites where the edge of the fill area is far from the property boundary, additional gas monitoring locations may be chosen to provide early detection so that corrective action can be taken to prevent gas migration from the landfill property.

Monitoring wells should be located along the property boundary in areas where gas migration is most likely to occur or to become a threat to the public or the environment. These wells should be located in critical areas such as between the landfill and adjacent buildings, groves of trees and sand or gravel bedded utility lines. Wells should be screened across geologic features that would be likely to transmit gas (sand seams, fracture zones, karst features, mine shafts, etc.). Monitoring locations should be spaced 100 to 500 feet apart, with the spacing dependent on the permeability of the ground (the more permeable, the closer the spacing) and on the number of nearby features that could be potentially damaged. Gas monitoring wells should not be placed directly opposite gas extraction wells on the fill area; monitoring wells may give a falsely low reading if they are in the zone of influence of the extraction well. Monitoring may not be necessary for areas where the potential for gas migration is low. For example, a stream or a valley may form a natural cutoff to prevent the flow of gas through the ground.

Monitoring wells should be designed to monitor unsaturated soil and rock down to an elevation equal to the bottom elevation of the landfill. Wells can be designed with a single riser perforated from just below the well seal to the bottom of the well, or can consist of a well cluster with each riser monitoring a different depth. Well clusters are valuable for detecting gas migration through separate distinct permeable zones.

Gas monitoring wells must be designed to prevent intrusion of atmospheric air into the wells at all times; the cap should have a valved sampling port for the direct attachment of the gas sampling instrument, so that samples may be drawn directly from the well.

Conclusions

All wells should be designed to minimize air intrusion into the system, which can dilute the sample, making it unrepresentative. Selection of well designs should be based upon what zones are to be monitored. Code and Micro wells work best for monitoring screened intervals more than 10 feet below the ground surface. Spike Probe wells work best in monitoring zones that are 10 feet or less below the ground surface.

References

Farquhar, Grahame, Monitoring and Controlling Methane Gas Migration, course notes presented at April 1993 Sanitary Landfill Design and Management training, offered by the University of Wisconsin, Madison, College of Engineering.

Missouri Department of Natural Resources, Flood Grant Team, An Analysis of Landfill Gas Monitoring Well Design and Construction.

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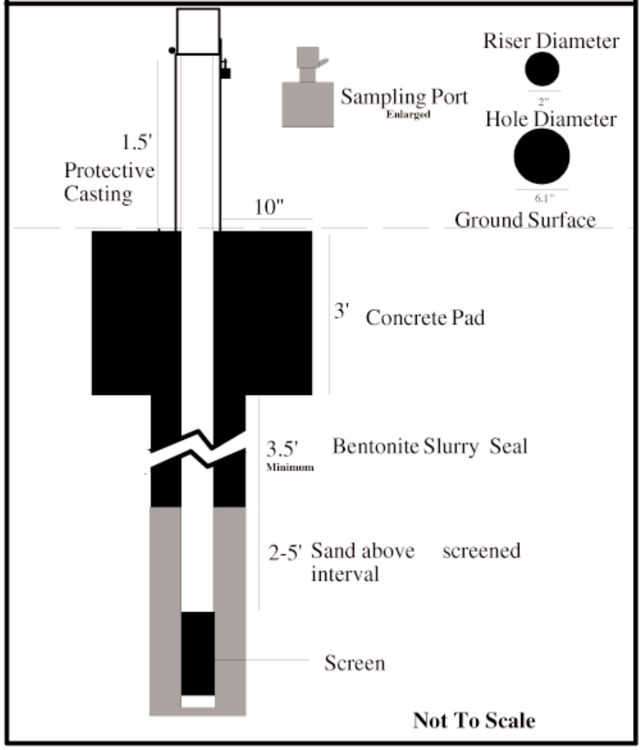
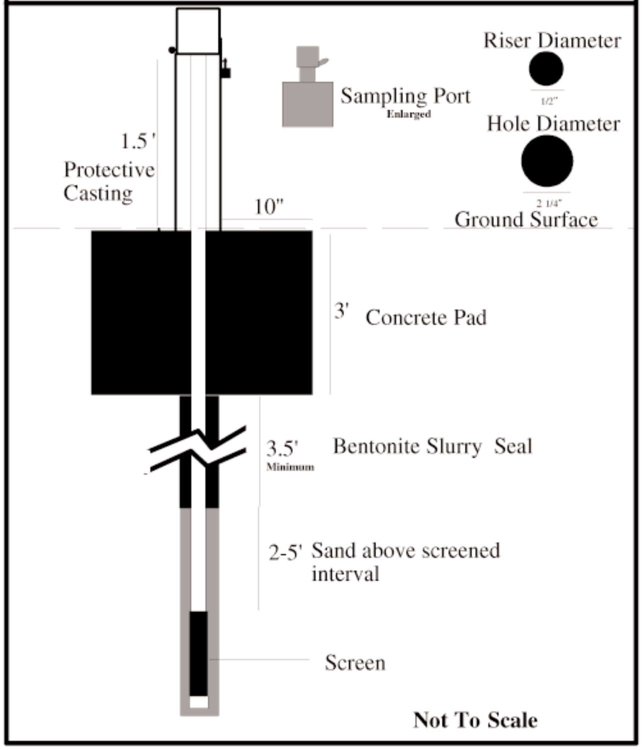
Technical Bulletin - Figure 1
Typical Code Well

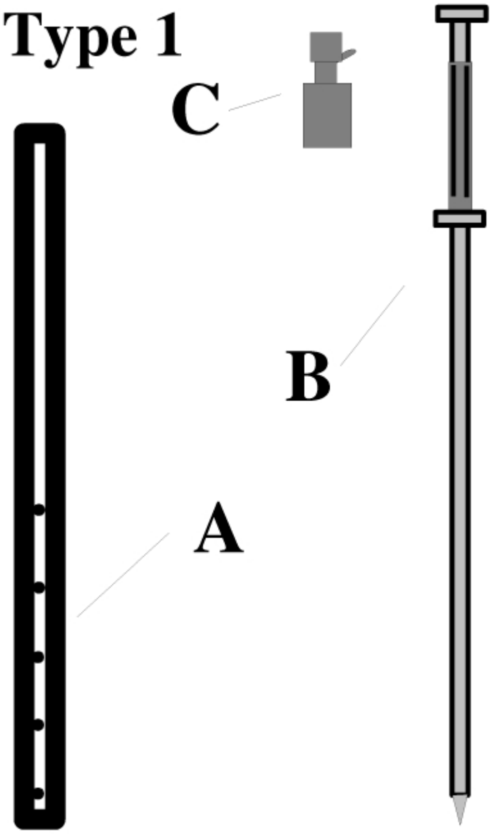


Technical Bulletin - Figure 2
Typical Micro Well



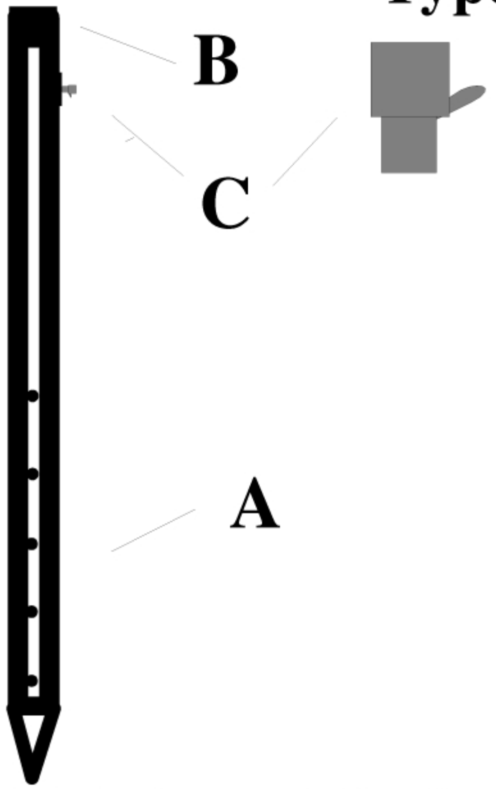
Technical Bulletin - Figure 3
Spike Probe

Type 1



<u>Part A Probe collector</u> - materials copper, steel or galvanized pipe. Holes drilled into pipe to within 1-2' of ground surface point.
<u>Part B Hammer Driver</u> - made of steel in which handle slides on rod to drive point into ground.
<u>Part C Sample Port</u> - made of numerous types; however, must be a compression fitting which remains closed after being disconnected.
Instructions for Use- Insert Part B into Part A. Then using the hammer driver pound Part B into the sellected sampling location. Be sure that the last set of holes on the Probe are at least 1' below ground surface. Install Part C onto Part A securly. Recommend solder or using a hot glue gun to insure air tight seal. Wait at least 1hour before attempting to sample.

Type 2



<u>Part A Probe collector</u> - materials steel or galvanized pipe. Holes drilled into pipe to within 1-2' of ground surface point.
<u>Part B Hammer Cap</u> - made of steel and is use to driving point.
<u>Part C Sample Port</u> - made of numerous types; however, must be a compression fitting which remains closed after being disconnected.
Instructions for Use- Screw Part B onto Part A. Then either hammer or push against Part B until probe is at proper debth. Be sure that the last set of holes on the Probe are at least 1' below ground surface. Install Part C onto Part A securly. Recommend threaded connections to insure air tight seal. Wait at least 1 hour before attempting to sample.

MISSOURI DEPARTMENT OF NATURAL RESOURCES

Procedures for Sampling Landfill Gas Inside Buildings

Technical Bulletin
9/1999

Division of Environmental Quality
Solid Waste Management Program

Overview

This document was prepared by the Missouri Department of Natural Resources' Solid Waste Management Program (SWMP) to provide guidance in how to properly sample for landfill gases in enclosed spaces.

Sampling Equipment

Proper selection of sampling equipment to be used for monitoring buildings is critical to make proper public safety assessments. Explosimeter-type instruments are appropriate for measuring methane in most monitoring in enclosed spaces. You should be aware that in an oxygen free environment some meters are not reliable and can give false readings that are lower than the actual gas concentrations.

It is recommended that detection instruments selected for monitoring buildings have a narrow sensitivity range, from 0-15 percent by volume for methane.

Sampling Procedures

Step 1 - Make sure the instrument has been properly calibrated to methane (Some instruments of this type are calibrated to hexane or propane, which have different combustible limits than methane). Prepare the instrument for sampling by allowing it to properly warm up as directed by the manufacturer.

Step 2 - Attach the hose to the instrument and begin sampling. Some instruments have metal wands that can be attached to the plastic hose to collect air samples. Wands can be made from copper tubing if not made available with the instrument.

Step 3 - To properly assess a building, samples should be collected from:

A. Around the walls of the building and electrical sockets
B. Closets or other enclosed wall spaces
C. Cracks in cement floors
D. Ceiling areas
E. Crawl spaces and basements
F. Areas where below ground utilities enter the building
G. Any other confined area

Step 4 - If landfill gas is detected by the instrument in any concentration it should be recorded and reported to the department.

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Sampling Times

Sampling times are almost as important as the procedure used to collect the sample. Proper monitoring of the site should include those times when landfill gas is most likely to migrate. For these reasons monitoring should be considered when:

A. Barometric pressure is low and soils are saturated; or
B. When snow cover is just beginning to melt; or
C. The ground is frozen or ice covered.

Regulatory Requirements

Sanitary landfills in operation after April 9, 1994, and all demolition landfills that applied for a construction permit after July 30, 1997, are required to conduct the quarterly monitoring of all buildings on site as required by 10 CSR 80-3.010(14) and 10 CSR 80-4.010(14).

These landfills must implement a gas monitoring program to ensure that regulatory limits for methane are not exceeded - 1.25 percent (25 percent lower explosive limit) by volume in buildings on site. Results must be submitted at least quarterly to SWMP in an electronic format.

The Solid Waste Management Regulations require that monitoring reports be submitted to SWMP at least quarterly. The SWMP recommends that gas monitoring be conducted during the months of February, May, August and November and that the results be submitted within 30 days of sampling. The data must be submitted in electronic form. The results submitted should contain:

1. The location of monitoring points.
2. Sample results obtained should include the date the sampling was performed and the barometric pressure, if available. Methane measurements may be given as a percentage of the total air volume or as a percentage of the Lower Explosive Limit (LEL). The following formula can be used to convert a percentage of LEL into a percentage methane by volume:

   $\%$ Methane (by volume) = LEL ($\%$) $\div$ 20

The form attached to the end of this bulletin may be used to record the information required by the department.

Corrective Action / Emergency Response

If methane gas levels exceed regulatory limits or are an obvious public safety threat, the landfill owner/operator must:

1. Immediately take all necessary steps to ensure protection of public health and safety. For accumulation of gas in buildings, either on-site or off-site, the operator must take appropriate action to mitigate the effects of the gas accumulation in those structures until a permanent remediation is completed.
2. Comply with the Solid Waste Management law and regulations as required by 10 CSR 80-3.010(14) and 10 CSR 80-4.010(14).

Conclusions

Missouri has stringent regulations governing landfill gas migration. Landfill gases that have the ability to migrate in buildings present a threat to public safety. It is the responsibility of the landfill owner/operator to take any and all steps to protect the public from migrating landfill gases both on- and off-site.

References

Farquhar, Grahame, Monitoring and Controlling Methane Gas Migration, course notes presented at April 1993 Sanitary Landfill Design and Management training, offered by the University of Wisconsin, Madison, College of Engineering.

SCS Engineers, Inc., April 1989, Procedural Guidance Manual For Sanitary Landfills, Volume II: Landfill Gas Monitoring and Control Systems, prepared for the California Waste Management Board.

United States Environmental Protection Agency, November 1993, Solid Waste Disposal Facility Criteria, Technical Manual, EPA 530-R-93-017.

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MISSOURI DEPARTMENT OF NATURAL RESOURCES

Sampling of Landfill Gas Monitoring Wells

Technical Bulletin
9/1999

Division of Environmental Quality
Solid Waste Management Program

Overview

This document was prepared by the Missouri Department of Natural Resources' Solid Waste Management Program (SWMP) to provide guidance regarding the quarterly sampling of gas monitoring wells as required by 10 CSR 80-3.010(14) and 10 CSR 80-4.010(14). This guidance applies to all landfills that monitor for methane migration by means of gas monitoring wells. Sampling results must be submitted at least quarterly to SWMP in an electronic format.

Sampling Equipment

Proper selection of sampling equipment is critical in obtaining true soil gas concentrations. Explosimeter-type instruments are not appropriate for measuring methane in gas monitoring wells, because the amount of oxygen which is present in the well may not be sufficient for the sample to "burn." These instruments will typically give false low readings when high concentrations of methane are present.

It is recommended that instruments used to sample gas monitoring wells have an automatic pump that has the ability to withdraw enough volume to bring a fresh sample of soil gas into the well. It is also beneficial that the instrument reads both oxygen and methane concentrations. Some instruments have the ability to read barometric pressure, which is also desirable.

Sampling Procedures

Step 1 - Make sure the instrument is properly calibrated. Prepare the instrument for sampling by allowing it to properly warm up as directed by the manufacturer.

Step 2 - Connect the instrument to the well head and begin collecting a sample.

Step 3 - Continue collecting the sample until the reading stabilizes. A stable reading is one that does not vary more than 0.5 percent by volume on the instrument's scale.

Step 4 - A proper reading should have 2 percent oxygen by volume or less. If levels of oxygen are higher, it may indicate that air is being drawn into the system giving a false reading of the true soil gas concentrations. Possible explanations for this problem are:
A. The gas monitoring well seal has failed;
B. Well head connectors are leaking; or
C. A connection at the instrument is leaking.

When the problem is eliminated repeat Steps 1-3. If the problem cannot be corrected, record those values and make sure that the problem is well documented in the report sent to the department.

PUB002053

Step 5 - Record the stabilized reading including the oxygen concentration and barometric pressure, if available.

Obtaining true soil gas concentrations from gas monitoring wells is dependent upon using a consistent proven method. If you have problems using the sampling procedures described, you should contact the department as soon as possible.

Sampling Times

Sampling times are almost as important as the procedure used to collect the sample. Proper monitoring of the site should include sampling at those times when landfill gas is most likely to migrate. Scientific evidence indicates that weather and soil conditions influence when gas will migrate. For these reasons sampling should be considered when:

A. Barometric pressure is low and soils are saturated; or
B. When snow cover is just beginning to melt; or
C. The ground is frozen or ice covered.

Records

The Solid Waste Management Regulations require that reports on data collected from wells be submitted to SWMP at least quarterly. The SWMP recommends that gas monitoring be conducted during the months of February, May, August and November and that the results be submitted within 30 days of sampling. The data must be submitted in electronic form. The results submitted should contain:

1. The location of monitoring points.
2. Sample results obtained should include the date the sampling was performed and the barometric pressure, if available. Methane measurements may be given as a percentage of the total air volume or as a percentage of the Lower Explosive Limit (LEL). The following formula can be used to convert a percentage of LEL into a percentage methane by volume:
   % Methane (by volume) = LEL (%) ÷ 20
3. The amount of time a well is pumped before a stabilized methane reading is taken.
4. The percent volume of O_2 (if the instrument used is capable of measuring).

The form attached to the end of this bulletin may be used to record the information required by the department.

Conclusions

Missouri has stringent regulations governing landfill gas migration. The department prefers to address the issue of migrating gases before they present a threat to public safety or the environment.

Migrating gases detected above allowable limits at property boundaries do not necessarily mean that there is an immediate threat to public safety. It does mean that there is a potential problem that must be addressed. In order to address such a problem, a permit modification to install a gas collection system may be necessary.

References

Landtec Landfill Control Technologies, Landfill Gas System Engineering Design: A Practical Approach, course notes from Landfill Gas System Engineering Design Seminar, 1994.

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