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 concentra-

tions 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 moni-

toring 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.

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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**.