Minnesota Pollution Control Agency

Guidelines for Monitoring for Landfill Gas at and Near Former Dumps

Remediation Division Voluntary Investigation and Cleanup, Emergency Response, Superfund, and Resource Conservation and Recovery Act Corrective Action Programs

Introduction

This document was developed in cooperation with the Minnesota Department of Health and staff at the Minnesota Pollution Control Agency (MPCA) Closed Landfill Programs to provide guidelines for the monitoring of methane associated with landfill gas (LFG) generated from abandoned unpermitted dumps that may pose risk to existing or proposed occupied structures. Non-methane organic compounds such as volatile organic compounds (VOCs) associated with historical releases at dumps (e.g., trichloroethylene, benzene, etc.) also may present in LFG, although the focus of this guidance principally concerns the monitoring of and response to methane hazards. Abandoned dumps are not included in the state legislation which provides for the cleanup of qualified landfills. The releases associated with abandoned dumps are commonly addressed by voluntary or responsible parties with the MPCA Superfund or Voluntary Investigation and Cleanup (VIC) Programs. Detailed guidance regarding the investigation, mitigation or long term management of subsurface landfill gas is beyond the scope of this document.

Generation and migration of landfill gas

Landfill gas (LFG) generated from landfills and abandoned mixed municipal dumps consists primarily of methane, carbon dioxide and smaller fractions of numerous other gases including nitrogen, oxygen and ammonia produced by the biodegradation of organic matter. This biodegradation is the result of the activity of microorganisms that are found naturally occurring in both wastes and soils. Methane can also be generated by naturally occurring buried organic deposits (e.g., peaty sediments) and can be difficult to distinguish from other methane sources.

Although the processes by which LFG is generated are similar at all dumps, considerable variability will exist between dumps in the amount of gas generated, the composition of the gas and the gas generation rate. Generally, methane generation is divided into four distinct phases:

Phase I

Upon initial placement of the waste, an aerobic phase develops characterized by rapid oxygen depletion as a result of increased microbial activity. This process can last for several months in larger dumps.

Phase II

At the end of Phase I, oxygen is depleted and anaerobic microbial activity is initiated, signaling the beginning of Phase II. During the anaerobic phase, leachate is produced, acidity is increased and there is a steady increase in hydrogen and carbon dioxide production.

Phase III

The start of Phase III is initiated by the production of methane gas. This is an anaerobic phase characterized by an accelerated increase in methane production with corresponding decreases in the levels of carbon dioxide, hydrogen, nitrogen, and acidity.

Phase IV

The final phase is characterized by a long period of methane production and waste degradation as methanogenic microorganisms reach steady state populations and gas constituent concentrations stabilize.

Methane generation may last from several years to decades. The length of the four phases of methane generation will vary considerably for different dump settings depending upon the amount of waste present, the composition of the waste material, moisture levels, temperature, and operational practices of the former dump.

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One of the most significant factors controlling waste degradation is moisture content. The mummified conditions observed at many dumps and landfills, as evidenced by the readability of old newspapers is directly related to a relative lack of moisture needed to promote degradation. Capping of a dump or landfill to reduce moisture infiltration will therefore, also reduce the rate of gas production and waste degradation. The presence of a cap also may essentially eliminate vertical LFG escape and promote lateral LFG migration.

Waste composition affects both the methane generation rate and the total amount of methane produced. Wastes containing higher biodegradable organic content, such as food waste, wood and paper, will produce more methane than more inert material such as concrete, bricks, plastic and glass. Typical municipal wastes products found in former dumps such as food and yard debris contain high amounts of biodegradable material that can result in high levels of methane generation.

Temperature also has an effect upon microbial activity. Generally, higher fill temperatures result in higher rates of methane production. The optimal temperature range for methane generation is between about 95ºF to 120ºF. Methane generation can be nonexistent at temperatures below 50ºF, which may be an important consideration in Minnesota.

Factors affecting LFG emissions and migration

LFG emissions to the atmosphere can occur via vertical migration through the surface cover of dump and/or at perimeter locations around the dump through a combination of lateral and vertical migration. LFG migrates from areas of high pressure to areas of low pressure, driven by subsurface and atmospheric pressure gradients. High pressure conditions are created within the waste mass of a dump when methane gas generation is taking place. Meteorological conditions can also affect the migration of LFG. Relative changes in barometric pressure may accentuate LFG pressure gradients in the subsurface around dump sites resulting in an increase in vertical and lateral gas migration, and a concomitant increase in the potential for vertical escape of emissions to the atmosphere.

LFG migration can be expected to occur laterally and vertically along preferential pathways where higher permeable native soils or fill are present or along buried utility corridors backfilled with coarser or aggregate than surrounding soils. Lateral LFG migration can be enhanced during winter months as vertical gas escape routes are limited by thick frozen soil columns typical of Minnesota winters. Similarly, at dump sites where impermeable covers, engineered caps or asphalt surfaces have been constructed the potential for lateral migration of LFG beyond the boundaries of the dump site can be enhanced although the resulting decrease of infiltrating moisture from impermeable caps should support lower organic degradation rates.

Environmental concerns of LFG

Environmental impacts of LFG and of methane gas in particular, can be separated into three main categories: imminent physical hazards, inhalation risks, and ecological impacts.

LFG hazards

The principal hazards associated with LFG are explosion and fire. There is a risk that methane can migrate laterally and vertically through the unsaturated soil column and collect in enclosed or confined spaces where a spark or other ignition source can trigger an explosion or fire. Methane presents an explosive hazard at concentrations between 5 percent and 15 percent by volume, in air. The lower and upper levels of the range of combustible gas concentration within which explosion may occur are defined for a specific combustible gas, and are known, respectively, as the Lower Explosion Limit (LEL) and the Upper Explosion Limit (UEL). The LEL for methane corresponds to five percent methane by volume in air, which is equivalent to a relative concentration of 50,000 parts per million (ppm) methane by volume. The UEL for methane is 15 percent methane by volume in air.

Inhalation risks

Risks associated with LFG inhalation can include both short term and long term exposure risks. Both of the two main LFG components, methane and carbon dioxide, are colorless and odorless, and have the capability to displace oxygen, which can result in conditions with the potential for asphyxiation. The accumulation of such lethal levels is especially a concern in confined spaces, such as underground utility structures and trenches, and within enclosed spaces and basements in buildings located at or adjacent to a dump or a landfill.

The short term effects of LFG inhalation can include headaches and irritability. Hydrogen sulfide, an odorous gas, which can be found at toxic levels in LFG, is an irritant to the eyes and respiratory system and can also be an asphyxiant. Long term inhalation risks may be associated with VOCs associated with LFG.

Ecological risks

LFG can stress or even kill plant life by displacing oxygen within the soil near the roots of plants. Crop damage can occur at farms near landfills. Additionally, although present in much smaller concentrations than methane and carbon dioxide, some non-methanogenic VOCs can contribute to the formation of ozone, a gas which, in addition to having deleterious respiratory effects, also can reduce plant growth and contribute to vegetation damage.

Landfill Gas Monitoring and Analysis

Preliminary subsurface methane surveys

Gas surveys should be conducted at abandoned dumps to assess methane risk levels to nearby or proposed structures. Due to the potential for changes in gas concentrations that may occur seasonally along with changes in moisture, ground temperature and frost conditions, LFG monitoring should be conducted at least three to four times per year. To the degree practicable, methane gas risks should be evaluated collectively based on sampling across the full extent of the dump including the dump perimeter during multiple sampling events rather than making conclusions on methane levels at one point in space and time. Low methane readings measured during one event at one location cannot be utilized to conclude that there is no problem. Monitoring needs to be more frequent near buildings in areas where explosive gases have been detected.

Preliminary LFG subsurface surveys can be conducted using temporary monitoring probes or permanent gas vents installed to allow for multiple sampling events. The construction of permanent gas probes may be required at high risk sites due to the fact that they are typically screened to penetrate the entire thickness of the waste fill from the base of waste to a few feet below the ground surface thus affording the ability to monitor over a greater cross-sectional area of the buried waste. An example sampling protocol for a gas probe is provided as Attachment A.

Monitoring of gas from a gas probe may be conducted utilizing portable combustible gas meters or by the analysis of gas samples. If a portable gas meter is utilized, it must be capable of quantifying the levels of methane gas as percent methane from zero to 100 by volume. The percent carbon dioxide and percent oxygen should also be recorded for each probe. Many available, portable combustible gas monitoring instruments are also capable of testing for other gases such as oxygen, carbon dioxide and hydrogen sulfide. The oxygen concentration is an important factor in gauging the potential for fires or explosions to occur in the waste or subsurface monitoring system.

Gas samples may also be collected in the field using an evacuated canister and analyzed by a private laboratory or a portable gas chromatograph by a mobile laboratory. Laboratory analysis provides accurate results than use of portable gas meters, especially for lower concentrations, however, field gas meters is more appropriate if the results are time critical. If landfill gas samples are collected using evacuated canisters for laboratory analysis the samples should be analyzed for both VOCs on the Minnesota Soil Gas List (refer to the MPCA vapor intrusion guidance) using U.S. Environmental Protection Agency (EPA) Method TO-15 and for methane. EPA Method 3C is a common laboratory method used for the analysis of fixed gases associated with landfill gas including oxygen, nitrogen, methane, and carbon dioxide.

Sampling locations need to address the full extent of the dump if practicable and the portion of the dump on the property under investigation. If LFG is known to be present at high levels within the waste area, there is a greater need to monitor along the perimeter of the dump, at properties adjacent to the dump and areas adjacent to nearby buildings.

Data on ambient conditions should be collected and documented when LFG data is collected including temperature, barometric pressure, weather conditions and any unusual conditions noted during the monitoring process.

Monitoring for LFG within buildings

General considerations

The presence of LFG and its potential to migrate to structures both on-site and adjacent to the site should be evaluated as part of every abandoned dump investigation. The evaluation should consider the potential for LFG, particularly methane, to migrate and accumulate within enclosed or confined spaces of commercial, industrial and residential buildings. This evaluation is best conducted by assessing both subsurface LFG levels in the vicinity of the buildings along with actual gas monitoring within buildings of concern. However, a thorough subsurface gas survey near buildings which typically should be conducted first will verify if gas is migrating towards and potentially within a building. This type of survey may eliminate the need for expanding the monitoring activities to the buildings. Alternatively, if thorough subsurface investigation for the presence of methane gases cannot be undertaken, or if levels of subsurface methane gas are very high on-site, an investigation for the presence of LFG within structures of concern should be conducted directly. If high soil gas levels are present at a site and potential for migration to structures on- or off-site exists, then an evaluation of the presence of LFG in these structures should be given a high priority. Monitoring for LFG should also be conducted along preferential pathways such as subsurface utility lines or trenches. Utility corridors should be carefully identified and located accurately on a site map. Authorities responsible for maintaining these utilities may need to be notified as the interior atmosphere of manholes, and other utility confined spaces, will require monitoring prior to entry.

Gas monitoring within buildings may represent an integral part of the investigative phase, may be an interim measure until gas controls are installed, or may be part of a long term program to ensure gas levels are not entering buildings or reaching levels of concern within those buildings.

Monitoring equipment

Currently there is a wide variety of combustible gas and gas specific monitoring equipment available featuring a broad range of precision. A summary of monitoring equipment that is used most commonly for soil gas assessments is presented in Table 1.

Certain combustible gas meters may not be capable of detecting gas concentrations in the low ppm range. Gas levels at these lower concentrations can be detected using sensitive combustible gas monitoring equipment, by collecting air samples for laboratory analysis or by using a combination of a portable flame ionization detector (FID) such as an organic vapor analyzer (OVA) and a photoionization detector (PID). An FID instrument will detect hydrocarbons present including combustible gases such as methane, whereas a PID cannot and will not be able to detect methane. Portable filters capable of screening out methane are also available for some OVAs. FID instruments used in this way to monitor for the presence of combustible gas should be designed to be intrinsically safe.

When gas monitoring is being conducted in a building where minor concentrations may be present, monitoring instruments may respond to the presence of combustible gas in the following manner: the reading on the monitor display may rise from zero ppm to a peak concentration and then drop off, perhaps back to a zero value. Care should be taken to record fluctuating levels at or above the UEL which can be registered by a field instrument in a similar way. The highest concentration should be recorded as this indicates a maximum concentration which accumulated in ambient air or observed at a port of entry. Concentrations above the UEL represent a significant concern as such levels can pose risks as both an asphyxiant and an explosive hazard when these levels drop below the UEL. The conditions under which the measurement was taken and meter fluctuations should be noted, however, as the degree of concern will be significantly higher if the gas concentration measured is relatively constant since a higher average air concentration will be indicated.

Continuous-read combustible gas sensors with alarms may be required at some buildings located near or on a source of LFG, particularly if methane has been detected in the buildings. These sensors should be capable of detecting combustible gas at least down to one percent LEL for methane and alarms should be set to signal or alarm if levels are detected in the range of 10 to 20 percent LEL, depending upon site specific conditions.

The level and type of monitoring required will need to be evaluated on a site-specific basis. Factors include: monitoring equipment available, the degree of concern for potential explosive hazards, levels of gas detected and the proximity of structures to waste sources and other site specific conditions. The degree of concern for a given structure also may depend upon whether the LFG is detected in or near an enclosed area, whether the LFG has the potential to build up to greater levels, the type of activities in or near the area where the gas is detected, and the proximity to the source of the LFG.

Documentation recommended during monitoring

Minimum documentation during LFG monitoring should include:

- the name and organization of the personnel conducting the monitoring
- a description of the potential ports of entry in the structure
- locations of possible confined or enclosed areas of the building
- the time and date that the monitoring activities took place
- the potential for sparking in enclosed areas and at or near the areas where gas was detected
- the type of monitoring equipment used and the minimum detection levels for the methane monitoring instruments used
- methods and time monitoring equipment was calibrated
- the locations and brief descriptions of monitoring locations
- all monitoring data
- temperature and barometric pressure are useful
- other pertinent observations

The level of documentation for follow-up monitoring events should be coordinated with the MPCA project staff.

Monitoring frequency

Acceptable monitoring frequency will vary considerably depending upon gas concentrations detected, the location of gas detections, the degree of concern and the potential for significant seasonal temperature and barometric fluctuations in the area of the site. At sites in which methane has been detected within a building or in the subsurface near a building, initial subsurface monitoring should be conducted quarterly at a minimum.

Levels of LFG in the low ppm level within manholes or within the soil gas near or adjacent to a structure may also need to be monitored routinely in order to evaluate the potential for temporal and seasonal fluctuations within the soil gas. A bi-monthly or monthly monitoring program may be needed at some sites during seasonal periods of peak gas movement. Peak gas movement is likely to occur during the period from November through April, when a frost cap is usually present. This period may be even longer if the site is located in northern Minnesota.

If the monitoring is occurring within a building, continuous monitoring using sensors and alarms may be appropriate, although the frequency will depend on site specific conditions. Frequent gas monitoring is recommended for buildings that are located close to LFG sources, at locations where consistently high gas readings have been observed, and where high exterior methane gas is detected near the structure. More frequent monitoring within buildings may be required where high levels of LEL are detected in the subsurface adjacent to the structure, within or at gas entry points within the structure or in the ambient air of the structure. Elevated ambient air methane concentrations represent a greater volume of LFG present in the structure and, therefore, a much greater potential explosive or asphyxiation hazard than similar methane levels detected at a port of entry. At particularly sensitive locations, the levels of gasses should be monitored with greater frequency during frost conditions.

Monitoring locations

Monitoring for gases within structures should include monitoring of both ambient air and specific port of entry locations. Before monitoring is conducted within a structure, it is necessary to evaluate the potential ports for gas entry into the structure, to identify confined or enclosed spaces within the structure, and evaluate the potential for sparking or ignition of gas, particularly within enclosed locations. Common ports of entry for gas that should be monitored include electrical conduits, elevator shafts, floor sumps, cupboards beneath first-floor sinks, cracks in concrete floors, and unsealed earthen floors such as sub-floor crawl spaces. Specific locations within structures identified as having LFG concerns should be monitored in at least two locations: low, near the floor or near the possible gas entry location, and high, along basement ceiling rafters or ceiling corners where methane gas, which is lighter than air, may have risen and become trapped.

Determining appropriate response actions

Tables 2 and 3 present recommended response actions based upon combustible gas measurements at a port of entry and in ambient air, respectively. The response actions presented in Table 2 and 3 are correlated to specific combustible gas concentration ranges. The higher "tiers" represents greater levels of potential concern and, therefore, corresponds to a higher level of response actions recommended in order to ensure gas concentrations are mitigated and public health and welfare is protected. The specific response to LFG within buildings may vary from that presented in Tables 2 and 3, depending upon site conditions, funding availability, type of equipment used, training of the personnel conducting the monitoring, and degree of access to properties. However, the recommended response actions presented should be viewed as both practical safeguards against potential LFG hazards and a framework within which site-specific responses may be developed.

As represented by a comparison of response actions between Table 2 and 3, the relative degree of concern is less if gas is detected only at a port of entry and is not detectable in ambient air. Gas levels detected at a port of entry, however, may represent a significant problem depending upon the levels detected, the potential for the gas to accumulate within an enclosed or confined space, proximity to sources of ignition, and the response time required to seal and eliminate the gas entry ports.

At any level of gas detected in a structure it is important to be able to determine if the gas is due to a utility line leakage or is LFG. If the gas is known to be LFG, all ports of entry should be identified and sealed, if possible, in order to eliminate this source. At higher gas concentrations, the fire department should be notified. Higher gas concentrations require an increased frequency of monitoring. This may be accomplished in part by use of a continuous read combustible gas sensor with alarms; however, some degree of follow-up monitoring with a portable meter is recommended in order to verify results and to address areas beyond the reach of the sensors. Routine inspection, calibration and maintenance of the continuous-read gas sensors should also be conducted as some sensors have been known to malfunction.

Higher gas concentrations may call for installing an active negative displacement fan ventilation system in the building or in rooms where gas has been detected. Active ventilation is especially recommended if ports of entry cannot be properly identified or sealed, or if gas concentrations cannot be mitigated by using other control measures. It is important that the ventilation results in a negative pressure being directed, if possible, on the source of gas or on a potential ignition source near where gas has been detected. Negative pressure will minimize the potential that gas within the building will be moved into other areas where it could potentially find an ignition source or displace air. If active negative ventilation is utilized as an interim gas control measure the ventilation system should be designed and installed by an experience professional and the ventilation should be able to mitigate gas concentrations to at least below one percent LEL for methane and preferably lower. If the ventilation system cannot mitigate gas to this level, either the ventilation system needs to be modified, other gas control levels need to be implemented, or evacuation need to be considered.

Long term use of negative pressure ventilation has the potential, however, of increasing the rate of vapor intrusion of LFG unless portals of entry of subsurface gas are identified and sealed. Once such portals have been sealed longer term building mitigation systems should be considered such as sub-slab depressurization or exterior gas control remediation and monitoring systems with contingency plans.

Where higher levels of combustible gas are indicated within a building, there is also an increased likelihood that a higher concentration of non-methane organic compounds may be present as well. Under these conditions, the gas composition should be determined by appropriate laboratory analytical methods due to the additional health risks posed by the inhalation of non-methane organic compounds.

Levels of combustible gas up at or greater than 10 of the LEL within the ambient air is cause for evacuation of a building if these levels cannot be mitigated immediately. Usually gas accumulates to such high levels only in confined or enclosed spaces. Unless these levels can therefore, be immediately mitigated by some means, persons should exit the building immediately. The decision to evacuate a building should be made in consultation with the local fire department. Additionally, each local fire department may have their own protocol for building evacuation and for reentering a building following evacuation. At a minimum, however, a building or an enclosed space with ambient gas concentrations 10 percent LEL of methane or greater should not be entered following evacuation except by a person properly trained and wearing the proper personal protective equipment and authorized by either the MPCA or the local fire department.

The tiered action steps outlined in Tables 2 and 3 are specifically designed for responding to combustible gas concentrations within buildings on or near a former dump. The MPCA Solid Waste Programs administers response actions at permitted landfills and response actions required under their program may be different from those described in Table 2 and 3. The tiered response actions are also not intended to replace a site-specific protocol for responding to combustible gas detected within buildings near landfills or former dumps, as each site is unique and local fire departments may have existing protocols that are both more specific and more conservative than the response actions presented. However, before implementing response actions employed at sites and buildings are less conservative than those presented within Table 2 or 3, however, prior approval should be obtained from the MPCA project staff.

Table 1. Compilation of common combustible gas monitoring equipment

Type of equipment	Measurement	Principle of operation	Description
Combustible Gas Detector	ppm, % LEL, % total gas	Combustible gases change resistance of a wheatstone bridge	1. Cannot be used in the presence of silicones, fuming acids, leaded gasoline vapors. 2. Not accurate in low oxygen or high CO_2 environments. 3. Relative humidity 10-90%. 4. Zero shift problem in ppm range. 5. Non-selective for gas.
Infrared Gas Analyzer	0 to 100% Methane, Oxygen, Carbon dioxide; also reads in % LEL	Computerized infrared analysis	1. All weather use from 14°F to 104° F. 2. May be battery operated. 3. Some instruments (e.g. several of the Landtec portable instruments) can also monitor for O_2 and CO_2 levels, and allows electronic data transfer using a data logger.
Flame Ionization Detectors (FID)	0 to 100 ppm to 5,000 ppm total organic vapors	Vapors are burned and the resulting ionization is measured	1. Will not distinguish between VOCs and other combustible gases such as methane without use of GC mode. 2. Not appropriate as a sole real time monitoring instrument for combustible gases without assumption VOCs absent. 3. When used in GC mode, there is no temperature control. 4. Not intrinsically safe, so use caution if there is a potential for approaching LEL levels.
Oxygen Meter	0% to 25% Gas	Atmospheric oxygen is measured on a galvanic cell	1. Corrosive environments may result in some damaged cells. 2. barometric pressure influences readings. 3. relative humidity range - 10 to 90%
Combination of FID and Photoionization Detector	0 to 500 ppm	PID - photoionization lamp ionizes gas and is measured	1. PID cannot detect methane; FID can detect combustible gases and other VOCs. 2. The difference in the two instruments readings.
Portable Gas Chromatograph	ppb, ppm	Column with FID, PID, or Electron Capture Device	1. Required for accurate ppb measurements. 2. Common in-field instrumentation for sampling probes.

Table 2. Combustible gas measured at a port of entry (applies even if no measureable gas in ambient air)

Tier	Combustible gas concentration at port of entry	Recommended response action
1	Up to 0.2% LEL (10 to 100 ppm)	Initiate or continue quarterly monitoring of ambient air and ports of entry with a portable meter by trained personnel. Identify sources of elevated readings; determine if gas is LFG, other VOCs or utility gas. Eliminate obvious spark sources, if possible, seal ports of entry if LFG is confirmed. A minimum of four rounds of non-detect LFG data, with at least one sample event during frost conditions, are needed before a decrease in monitoring frequency may be requested.
2	0.2 to 2% LEL(~100 to 1,000 ppm)	Continue or initiate Tier 1 actions. Increase monitoring frequency to monthly. Subsurface methane levels should be investigated near the building. Notify the local fire department.
3	2 to 10% LEL (~ 1,000 to 5,000 ppm)	Verify results the following day. Initiate or continue Tier 1-2 actions. After sealing ports of entry, confirm effectiveness by daily monitoring for at least one week, then monthly based upon monitoring results. Initially, monitoring with a portable meter should be conducted at least monthly until levels are reduced. Continuous-read combustible gas sensors with alarms may replace or augment monthly monitoring with a portable meter; monitoring with a portable meter should continue at least quarterly. A minimum of two sensors is recommended: one high, at ceiling level or along ceiling rafters, and one at floor or sub-floor level. Gas alarms should be set no higher than 10 % to 15% of the LEL. Active fan ventilation may be called for if control measures are not able to reduce gas levels to less than 1% LEL
4	10 to 50 % LEL (~5,000 to 28,000 ppm)	Initiate or continue control measures (sealing ports of entry, possible installation of active fan ventilation) and site investigation actions outlined for Tiers 1-3. Install a positive displacement fan ventilation system. If control measures cannot reduce levels to less than 1% LEL, the ventilation system or other controls must be modified. Alert the local fire department of potential explosive hazard.
5	50% LEL or greater (greater than 28,000 ppm)	Evacuation may be recommended, depending upon site conditions, the potential for explosive hazards, and ability to immediately implement successful control measures outlined in Tiers 1-4.

Table 3. Combustible gas measured in ambient air

Tier	Combustible gas concentration in ambient air	Recommended response actions
1	Up to 0.1% LEL (10 to 50 ppm)	Initiate or continue quarterly monitoring of ambient air and ports of entry with a portable meter by trained personnel. Identify sources of elevated readings; determine if gas is LFG, other VOCs or utility gas. Eliminate obvious spark sources, if possible, and seal ports of entry if LFG confirmed. A minimum of four rounds of non-detect LFG data, with at least one sample event during frost conditions, are needed before a decrease in monitoring frequency may be requested.
2	0.1 to 0.2 % LEL (50 to 100 ppm)	Continue or initiate Tier 1 actions. Install continuous read combustible gas sensors with alarms. A minimum of two sensors is recommended: one high, at ceiling level or along ceiling rafters, and one at floor or sub-floor level. Gas alarms should be set no higher than 10% to 15% of the LEL. Verification with a portable meter should be conducted at least weekly. Evaluate other potential receptors. Subsurface methane levels should be investigated in the vicinity of the building. Notify the local fire department.
3	0.2 to 1 % LEL (100 to 500 ppm)	Continue or initiate control measured outlined in Tiers 1 and 2. Install positive displacement fan ventilation system to create positive pressure in the structure. Confirm effectiveness of ventilation system by daily monitoring with a portable meter for at least one week.
4	1 to 10 % LEL (~500 to 5,000 ppm)	Continue or initiate control measures outlined in Tiers 1-3 immediately to mitigate gas levels. If ventilation system has been installed and the gas levels are not controlled to less than 1% of the LEL, the ventilation system is not operating properly and must be adjusted or amended. Alert the local fire department of potential explosive hazard[2]. Evacuation of rooms or building may be warranted as levels approach 10% LEL, depending on site conditions and the response time needed to reduce gas levels.
5	10% LEL or greater (~ 5,000 ppm or greater)	Immediately alert fire department. Evacuation of building is recommended immediately. Only trained personnel can enter building until levels have been reduced to less than at least 10% LEL and preferably not until gas levels have been reduced to less than 1% LEL. Ventilate building and implement other control and site investigation measures outlined in Tiers 1-4. Continuous gas sensors should have displays which can be monitored from central locations both inside and outside the building.

Appendix A

Example Combustible Gas Sampling Protocol[1]

The following sampling protocol for gas probes should be viewed as the minimum procedures to be used when collecting samples from gas probes at or near abandoned dumps for the presence of methane.

Minimum Instrument Requirements:

The combustible gas measuring instrument selected must be calibrated to the manufacturer's specifications and must have the capability to measure percent methane from zero to one hundred percent by volume to accuracy within plus or minus one-half of one percent.

Minimum Testing Requirements:

A gas probe test shall at a minimum be conducted in the following manner:

The instrument hose should be connected to the probe spigot, then to the instrument pump, and the spigot valve should both be opened simultaneously.

The sample shall be drawn for at least five minutes. In the five minute period the maximum methane concentration shall be recorded as percent methane (not as percent of the LEL). The steady state methane concentration shall also be recorded if achieved. If no steady state is reached in the original five minute period an additional five minutes of test shall be conducted. When the steady state (i.e., variability of less than five percent over a 10 second period) is reached it should be recorded. If not steady state is reached in the ten minute period it should be recorded as "no steady state reading achieved."

In addition to the methane concentration, the percent carbon dioxide, and percent oxygen should also be recorded, if possible, for every probe.

At least once during the sampling event, the barometric pressure and ambient temperature shall be recorded. Record other weather conditions and any other per[2]tinent information as appropriate.

[1] This protocol is based on recommended procedures in use in the MPCA Closed Landfill Program.