APPENDIX A

BASICS OF LANDFILL GAS

Basics of Landfill Gas (Methane, Carbon Dioxide, Hydrogen Sulfide and Sulfides)

Landfill gas is produced through bacterial decomposition, volatilization and chemical reactions. Most landfill gas is produced by bacterial decomposition that occurs when organic waste solids, food (i.e. meats, vegetables), garden waste (i.e. leaf and yardwaste), wood and paper products, are broken down by bacteria naturally present in the waste and in soils. Volatilization generates landfill gas when certain wastes change from a liquid or solid into a vapor. Chemical reactions occur when different waste materials are mixed together during disposal operations. Additionally, moisture plays a large roll in the speed of decomposition. Generally, the more moisture, the more landfill gas is generated, both during the aerobic and anaerobic conditions.

<u>Landfill Gas Production and Composition</u>:

In general, during anaerobic conditions, the composition of landfill gas is approximately 50 percent methane and 50 percent carbon dioxide with trace amounts (<1 percent) of nitrogen, oxygen, hydrogen sulfide, hydrogen, and nonmethane organic compounds (NMOCs). The more organic waste and moisture present in a landfill, the more landfill gas is produced by the bacteria during decomposition. The more chemicals disposed in a landfill, the more likely volatile organic compounds and other gasses will be produced.

<u>The Four Phases of Bacterial Decomposition</u>:

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

<u>Phase I:</u>

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

<u>Phase II:</u>

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

Phase III:

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

Phase IV:

Phase IV decomposition begins when both the composition and production rates of landfill gas remain relatively constant. Phase IV landfill gas usually contains approximately 45 percent to 60 percent methane by volume, 40 percent to 60 percent carbon dioxide and 2 percent to 9 percent other gasses, such as sulfide. Gas is produced at a stable rate in Phase IV, typically for about 20 years; however, gas will continue to be emitted for 50 or more years after the waste is placed in the landfill (Crawford and Smith 1985). Gas production might last longer, for example, if greater amounts organics are present in the waste, such as at a landfill receiving higher than average amounts of domestic animal waste" (ATSDR, 2001).

Due to the fact that refuse is placed in a landfill at different times and consists of different types of solid waste at different moisture content, all four phases of degradation may be occurring simultaneously within the landfill.

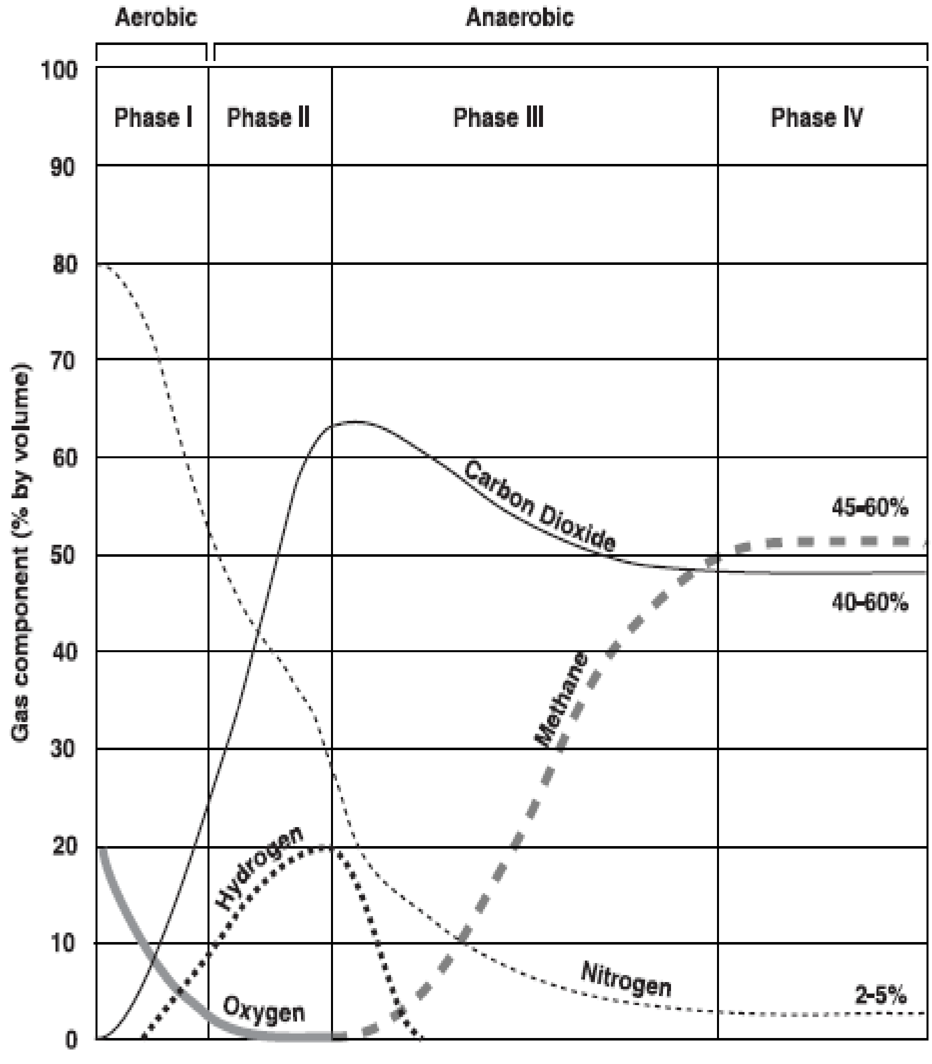
Factors Affecting Landfill Gas Production:

Gas production rates depend on the rate of decomposition, which in turn is affected by moisture content of the waste, temperature, soil cover permeability, amount of precipitation, composition of the waste, refuse particle size, compaction, and landfilling practices.

Moisture is essential for bacterial survival. Ideal moisture content for decomposition is one that approaches saturation. Biological reactions can be retarded if moisture content drops below 40 percent and essentially stops when moisture content is below 20 percent. Thus, in very dry climates, methanogenic (methane producing) decomposition will have a very small possibility of occurring. Methane will be produced only when oxygen (O_2) is no longer present in the landfill.

Capping of a landfill with a low permeability layer reduces the available moisture, thus retarding landfill gas production. Smaller particles decompose more quickly due to the high surface area to mass ratio. Thus, shredded waste produces gas more quickly than non-shredded waste. For additional information on landfill gas production and composition refer to Chapter 7 of MassDEP's "Landfill Technical Guidance Manual"
(http://www.mass.gov/dep/recycle/laws/policies.htm).

Figure 1: Production Phases of Typical Landfill Gas



Note: Phase duration time varies with !andfi!! conditions

Source: EPA 1997

<u>Hydrogen Sulfide and Sulfides</u>:

Sulfides are naturally occurring gasses that often give a landfill gas mixture its rotten egg smell. Sulfides can cause unpleasant odors even at very low concentrations. Hydrogen sulfide is a colorless, flammable gas and is one of the most common sulfides responsible for landfill odors. Some people can smell hydrogen sulfide (individual's odor threshold) at concentrations as low as 0.5 parts per billion (ppb). However, the odor threshold can vary significantly among individuals based on the olfactory sensitivity of the person. For many compounds, including hydrogen sulfide, there is a wide variability in published odor thresholds (refer to Table 1). Odors alone cannot be relied upon as providing an early warning for elevated concentrations of hydrogen sulfide. "*At concentrations around 100 ppm,"* (parts per million) *"no odor is detected due to a loss of olfactory sensation, resulting in loss of warning properties at lethal levels.*" (Integrated Risk Information System (IRIS)). Hydrogen sulfide is more dense than air, and therefore, more likely to pool at lower elevations under still conditions, depending upon topography.

Hydrogen sulfide is found naturally in the environment and is also produced from man-made processes. Hydrogen sulfide occurs naturally in crude petroleum, natural gas, volcanic gasses, hot springs, and tidal flats and can also be produced from bacterial breakdown of organic matter. Hydrogen sulfide is produced by human and animal waste, and landfilling of solid waste, and can result from industrial activities such as food processing, coke ovens, paper mills, tanneries and petroleum refineries, to name a few.

Dimethyl sulfide and mercaptans are sulfides that can also cause odors but typically are not emitted from a landfill at the high concentrations or at production rates associated with hydrogen sulfide.

The concentration of hydrogen sulfide detected in landfill gas samples at solid waste landfills that receive construction and demolition (C&D) waste is usually much higher than at landfills that do not accept C&D. The higher concentrations of hydrogen sulfide are believed to be associated with the gypsum board component (e.g. wallboard) present in C&D material. The combination of gypsum, organic material, moisture and anaerobic conditions present in C&D landfills is believed to provide a favorable mixture and environment for bacteria to produce hydrogen sulfide gas. Concentrations of hydrogen sulfide detected in raw landfill gas samples, collected from within a landfill waste mass, have ranged from 50,000 ppb to 15,000,000 ppb (50 ppm - 15,000 ppm) for those landfills that accepted C&D solid waste. Landfills which do not accept C&D typically have much lower concentrations of hydrogen sulfide in the raw gas, usually less than 100,000 ppb (100 ppm).

Hydrogen sulfide is generated as a result of a series of reactions that biologically reduce sulfate leached from gypsum contained in the C&D. In general, wallboard consists of the gypsum core ($CaSO_4$ x $2H_2O$) with facing and backing consisting of paper. The microorganisms responsible for generating hydrogen sulfide include sulfate-reducing bacteria and sulfur-reducing bacteria (Florida, 2002). Sulfate reducing bacteria require the following to produce hydrogen sulfide: a sulfate source (gypsum), a carbon source (organic material), anaerobic conditions, and moisture.

Laboratory studies have indicated that under anaerobic conditions "*...decaying drywall, even alone, leached enough sulfide ions and organic matter for sulfate reducing bacteria to generate large hydrogen sulfide concentrations*" (Florida, 2002). "*Factors contributing to hydrogen sulfide production are anaerobic conditions, pH, moisture, organic matter content, in the presence of sulfate*" (Florida, 2002). Additional information on factors affecting hydrogen sulfide production is available from the State University System of Florida.

Hydrogen sulfide production from various mixtures of municipal solid waste ("MSW") and C&D waste has been measured under laboratory conditions. Laboratory experiments have documented higher sulfide production from wastes with wallboard than in those without.

Table 1. Chemical and Physical Properties of H_2S

Characteristic/Property	Data	Reference
Common Name	hydrogen sulfide	ATSDR, 1999
Synonyms	hydrosulfuric acid; stink damp; sulfur hydride; sulfurated hydrogen; dihydrogen monosulfide; sewer gas; swamp gas; rotten-egg gas	ATSDR, 1999
CAS Registry No.	7783-06-4	ATSDR, 1999
Chemical Formula	H_2S	ATSDR, 1999
Molecular Weight	34.08	ATSDR, 1999
Physical State	colorless gas	ATSDR, 1999
Odor Threshold	0.0081-0.13 ppm	Beauchamp et al., 1984; Amoore and Hautala,1983
	0.005 ppm	U.S. Department of Health and human services, 1999
Vapor Pressure	220 mm Hg at 21.9°C	ATSDR, 1999
Density	1.5392 g/L at 0°C	ATSDR, 1999
Specific Gravity	1.192	ATSDR, 1999
Freezing/Boiling/Flash Point	-85.49°C/-60.33°C/26°C	ATSDR, 1999
Solubility	1 g in 242 mL water at 20°C; soluble in alcohol, ether, glycerol, gasoline, kerosene, crude oil, carbon disulfide	ATSDR, 1999
Conversion factors in air	1 ppm = 1.4 mg/m^3 1 mg/m^3 = 0.7 ppm	AIHA, 1991

Methane and Carbon Dioxide:

Landfill gas is composed primarily of 50 percent methane and 50 percent carbon dioxide and other gases produced at less than 1 percent. Methane and carbon dioxide are generated through the biological decomposition of waste. Methane is naturally occurring flammable, colorless and odorless gas and is the principal explosive component of concern in landfill gas. Carbon dioxide is naturally found at low concentrations in the atmosphere. Carbon dioxide is colorless, odorless, and slightly acidic.

Table 2. Chemical and Physical Properties of Methane

Characteristic/Property	Data	Reference
Common Name	Methane	Handbook of Chemistry and Physics, 2001
Synonyms	natural gas, marsh gas, fire damp, methyl hydride	Sax's Dangerous Properties of Industrial Materials, 2000
CAS Registry No.	74-82-8	Handbook of Chemistry and Physics, 2001
Chemical Formula	CH_4	Handbook of Chemistry and Physics, 2001
Molecular Weight	16.04 g/mol	Handbook of Chemistry and Physics, 2001
Physical State	colorless gas	Sax's Dangerous Properties of Industrial Materials, 2000
Odor Threshold	Odorless	Sax's Dangerous Properties of Industrial Materials, 2000
Density	0. 7168 g/l	Sax's Dangerous Properties of Industrial Materials, 2000
Freezing/Boiling/Flash Point	-183°C/-162°C/-188°C	Hawley's Condensed Chemical Dictionary, 2001
Solubility	Slightly soluble in water (v/v at 20°C is 0.033); soluble in alcohol, and ether	Hawley's Condensed Chemical Dictionary, 2001
Flammability Limits in Air	5% to 15%	Hawley's Condensed Chemical Dictionary, 2001

2.1.5 Hydrogen Sulfide Gas Generation Rates Vs. Methane Generation Rates:

C&D debris landfills do not produce the large volumes of methane gas that MSW landfills generate**.** The lower methane production can be a problem since one of the most effective treatment technologies for landfill gas (including hydrogen sulfide) is combustion using methane as the fuel source. The lower methane production may be because the landfill may not have reached anaerobic conditions, which are necessary for significant methane and hydrogen sulfide production. Additionally, hydrogen sulfide is toxic to methane producing bacteria, which in turn reduces methane gas production even under anaerobic conditions. Combustion technologies such as an active landfill gas collection and landfill gas flare system require sufficient fuel (methane) in order to thermally treat the hydrogen sulfide gas.

MassDEP has noted a correlation between the acceptance of C&D at both active landfills and at unlined landfill closure projects and the generation of hydrogen sulfide causing odors offsite. Some landfills that accepted mostly unprocessed C&D for disposal have experienced hydrogen sulfide odors offsite as early as fourteen months from first acceptance. Since the large surface area of processed materials promotes rapid decomposition, MassDEP has experienced hydrogen sulfide gas emissions offsite as early as nine months from the first acceptance of processed C&D fines and residuals used for grading and shaping material for unlined landfill closure projects.

MassDEP strongly recommends that, when disposing of unprocessed C&D or processed C&D (fines and residuals) in an active landfill, the owner/operator accept other materials (MSW) for disposal that generate sufficient levels of methane to properly control the generation of hydrogen sulfide gas.

With regard to the Inactive Unlined Landfill Closure projects, where C&D fines and residuals are accepted for grading and shaping, MassDEP recommends mixing soils with the C&D fines and C&D residuals at a minimum ratio of 1 to 1 by volume in order to reduce the potential for generation of hydrogen sulfide (less surface area).

Landfill Gas Migration:

Landfill gas that is produced within the landfill mass will generally move away from the landfill. Landfill gasses can migrate through the soils or through ambient air (dispersion). The production of landfill gas results in pressure gradients (advection) and concentration gradients (diffusion) between the landfill and the surrounding environment. Landfill gas will migrate from the source area (landfill) along the path of least resistance due to pressure, density, and concentration gradients. Methane is lighter than air and carbon dioxide is heavier than air. However, they *"... will not separate by their individual density..*", but rather move, "*.. as a mass in accordance with the density of the mixture and other gradients such as temperature and partial pressure*" (EPA, April 1992). This usually results in landfill gas moving upward through the landfill surface into the landfill gas collection system or through the surface soils into ambient air. However, the upward movement of landfill gas can be inhibited by compacted waste or landfill cover materials. This can result in landfill gas migrating horizontally through the waste mass into surrounding soils, utility conduits or structures if an adequate gas collection system is not designed and constructed.

Factors Affecting Landfill Gas Migration:

Landfill gas has been detected in soils at distances of up to 1,500 feet from the edge of waste at landfills. As with groundwater flow, highly porous materials, such as fine to coarse sands and gravels, will provide more passageways for landfill gases than fine-grained soils such as till, silts and clays.

However, landfill gas migration differs from migrating contaminated groundwater in that gas flows within the soils along its own pressure and concentration gradient, which can cause gas migration in a direction opposite to groundwater flow or topography. Also, landfill gas flow in soils is impeded by soils that are saturated. For example, wetlands and other locations where exposed groundwater is situated, act as barriers to the migration of landfill gas. The water table (non perched) is a barrier to landfill gas migration. Perched water table conditions, however, do not prevent landfill gas from migrating through soils located in between the perched water table interval and underlying water table.

Landfill gasses can move through the landfill surface to the ambient air. Once in the air, landfill gasses can be carried off site to receptors by the wind. Odors are an indicator of gas moving in ambient air. The concentration of gases in ambient air, where people may be exposed, depends on many factors including, but not limited to: proximity to the landfill, landfill gas production rates, landfill gas constituent concentrations within the landfill, pressure gradients within the landfill, gas control systems, topography, weather (e.g. barometric pressure, wind), and change in seasons (temperature inversions) to name a few.

Additional information on landfill gas migration through soils is available within MassDEP's Landfill Technical Guidance Manual, U.S. Environmental Protection Agency's, *Design Operation, and Closure of Municipal Solid Waste Landfills*, *seminar publication*, EPA/625/R-94/008, and in the document titled *Landfill Gas Primer, An Overview For Environmental Health Professionals*, November 2001 prepared by Agency for Toxic Substances and Disease Registry (http://www.atsdr.cdc.gov/HAC/landfill/html)

APPENDIX B

Landfill Gas Monitoring

Landfill Gas Monitoring

This Appendix provides basic information about the design and implementation of landfill gas sampling and monitoring at landfills. Chapter 4 of MassDEP's *Landfill Technical Guidance Manual* ("Manual") provides guidance on implementing landfill gas monitoring at landfills including soil gas monitoring procedures. Additionally, MassDEP recommends the following document as an overview of the different types of landfill gas monitoring:

Landfill Gas Primer
An Overview for Environmental Professionals
November 2001

prepared by

Department of Health and Human Services
Agency for Toxic Substances and Disease Registry
Division of Health Assessment and Consultation
(www.atsdr.cdc.gov/HAC/landfill/html)

MassDEP recommends that professionals experienced with landfill gas monitoring procedures and protocols, and the regulations, be consulted when planning landfill gas monitoring activities at landfills.

Ambient Air Monitoring Locations

MassDEP recommends a pre-sampling survey be conducted prior to selecting ambient air monitoring locations. Inspecting the area surrounding the landfill is necessary to identify receptors (e.g. residents, health-care facilities, schools, day-care centers, businesses, etc.). Of primary importance in ambient air monitoring is the predominant wind direction for the area. Conducting some preliminary field screening and identifying other potential sources of hydrogen sulfide (e.g. vehicles, landfill equipment, flares, industrial sources) and other pollutants is also recommended. Background samples should be collected upwind of the landfill.

The topography of the surrounding area is very important in determining where to monitor. In some circumstances topography and local atmospheric conditions may cause landfill emissions to travel significant distances (a mile or more) before affecting off-site receptors. This is more likely to occur at large, highly mounded, landfills or in areas with significant elevation changes. Under these circumstances monitoring the fence line may be too close to the landfill to detect landfill gas emissions.

Landfill gas will tend to collect in low-lying areas under certain atmospheric conditions (e.g. low wind, high humidity, etc.). Methane is lighter than air and carbon dioxide is heavier than air. However, landfill gas "*..will not separate by their individual density….*", but rather moves, "*as a mass in accordance with the density of the mixture and other gradients such as temperature and partial pressure*" (EPA, April 1992).

MassDEP will require each owner/operator, as part of their Hydrogen Sulfide and Odorous Landfill Gas Response Plan ("Plan"), to include a section on monitoring locations (on-site and off-site) for their Landfill. MassDEP refers to this section of the Plan as the Odor Survey Plan or Odor Loop.

Meteorological Considerations

MassDEP recommends a modest local meteorological data collection station be installed at the Landfill site that documents wind speed and direction, barometric pressure and temperatures. Wind direction and speed can vary significantly over short distances. Meteorology can vary from location to location and greatly affect where and at what concentrations contaminants are present in ambient air. MassDEP has noted a strong correlation between certain types of atmospheric conditions and odor complaints at many landfills. Odor complaints tend to coincide with little or no wind, fog or high humidity, overcast skies, and during thermal inversions. These meteorological conditions tend to occur early in the morning or evening. These types of weather conditions typically occur during the change in season from Fall to Winter and from Winter to Spring. Odor complaints are rarely received during clear, sunny, and windy days.

Near Surface Monitoring

Near surface monitoring is the measurement of gas concentrations within a few inches of the surface of a landfill. Near surface monitoring is used to quantify the levels of landfill gas that are escaping from the landfill surface, to verify a cover system integrity and performance or to determine whether the landfill gas control system is working efficiently to control landfill gas emissions. Near surface monitoring is a useful tool to evaluate the effectiveness of landfill gas control systems and identify those areas contributing to landfill gas emissions. A screening study consisting of landfill gas characterization (refer to the "Landfill Gas Characterization" section of this Appendix) followed by near surface monitoring can be useful in narrowing down the list of potential compounds causing odors and their source (e.g. gas breakouts along a particular landfill slope).

Near surface monitoring is more commonly conducted at those landfills that trigger the New Source Performance Standards (NSPS - 40 CFR 60, subpart www) under the Clean Air Act with NMOC (nonmethane organic compounds) emissions greater than 50 Mg/year. For those landfills, a quarterly surface methane monitoring program is required. The protocol for assessing surface emissions is included in the Federal NSPS guidelines 40 CFR 60.755. Portable instruments are used for evaluating landfill cover systems by monitoring for methane leaks. For the facility to be considered in compliance, the monitoring program requires that the methane concentration be less than 500 ppm above background at the surface of the landfill. To determine if this level is exceeded, the owner and/or operator shall conduct surface testing around the perimeter of the collection area and along a grid pattern that traverses the landfill at 30 meter intervals and where visual observations indicate possible elevated concentrations of landfill gas, such as distressed vegetation and cracks or seeps in the cover material. A surface monitoring design plan shall be developed that includes a topographical map with the monitoring route and the rationale for any specific deviations from the 30 meter grid intervals (40 CFR 60).

This near surface monitoring methodology can be used to identify hydrogen sulfide as well as methane emissions. Near surface monitoring is accomplished with portable sampling equipment with the probe inlet positioned to within 5 to 10 centimeters of the ground surface. The probe is moved over the surface of the landfill at a pace slow enough to identify peak hydrogen sulfide/methane/volatile organic compounds concentrations. Whenever landfill gas is identified, the pace is slowed further and the area assessed to locate the local maximum concentration. MassDEP recommends that monitoring be performed under the following conditions: no precipitation, wind speeds below 10 miles per hour, and low barometric pressure.

Landfill Gas Characterization

Landfill gas characterization is the measuring of the concentration of gasses from the interior of the landfill. Landfill gas characterization samples are collected from within the waste mass, unlike soil gas monitoring samples that are collected from soils above or adjacent to the landfill. Landfill gas characterization is typically performed to identify the individual chemicals of concern in the raw landfill gas. Landfill gas characterization is typically done to quantify the concentrations of methane, carbon dioxide, volatile organic compounds, sulfide and mercaptans in raw landfill gas. Landfill gas characterization is performed to aide in the design of a landfill gas control system and aide in the routine balancing of an active landfill gas control system. Landfill gas characterization data is required for certain air quality permitting and can be important for modeling landfill gas emissions and determining the feasibility of a potential post closure use at a landfill.

Landfill gas characterization samples are typically collected from landfill gas vents installed as part of a landfill gas control system. If a landfill gas control system is not in place, landfill gas samples are collected from shallow probes/wells installed within the waste mass (refer to Chapter 4 of the Manual). Sampling procedures for landfill gas characterization are presented in the Manual.

Landfill gas characterization samples, including samples for hydrogen sulfide, are typically analyzed using a combination of field equipment and laboratory analysis. First, field equipment such as multigas meters and Jerome meters are used for quantifying hydrogen sulfide concentrations in landfill gas and then samples are collected for laboratory analysis. The choice of which field equipment to use depends on the detection limits of equipment and the concentrations of hydrogen sulfide detected in the raw landfill gas. Multigas meters typically have the detection range of 1 ppm - 2000 ppm for hydrogen sulfide compared with a Jerome meter, which has the detection range of 0.003 ppm to 50 ppm. MassDEP does not recommend the use of Draeger tubes for assessing hydrogen sulfide concentrations.

MassDEP recommends that, prior to the collection of landfill gas samples for laboratory analysis, portable field equipment (e.g. multigas meter, photo ionization detector etc.) be used to analyze the landfill gas from the proposed sampling locations for methane, volatile organic compounds, hydrogen sulfide and oxygen. The purpose of analyzing in the field is to ensure that a representative and undiluted raw landfill gas sample is collected from the sampling locations (refer to the Manual). The field data can be used to identify problems (e.g. oxygen intrusion) before samples are collected for costly and time-consuming laboratory analysis. Additionally, the field data can be compared to laboratory data in order to ensure proper quality assurance/quality control procedures have been followed. After analyzing the landfill gas with field equipment, a gas sample for laboratory analysis is typically collected in a SUMMA canister or Tedlar bag. The presence of high concentrations of oxygen in the laboratory sample may be an indicator of atmospheric contamination of the sample. As always, proper collection procedures and holding times for the particular test method need to be followed.

Ambient Air Monitoring Protocols for Hydrogen Sulfide

MassDEP has established Action Levels for hydrogen sulfide in ambient air (refer to Table 1 in the policy "*Control of Odorous Gas at Massachusetts Landfills*" (the "Policy")). In order to determine if a hydrogen sulfide Action Level has been exceeded, ambient air monitoring equipment must be employed. Please note that the determination of an odor nuisance condition can be entirely separate from determining the ambient air concentrations of hydrogen sulfide. Hydrogen sulfide is only one of many compounds that could be emitted from a landfill that may cause an odor nuisance. For information on determining if odors from landfill gas emissions pose a nuisance (Odor Action Level 1) refer to Appendix E- "*Protocol for the Assessment of Off-site Landfill Odors*".

MassDEP recommends the following equipment and protocols be used for determining if hydrogen sulfide concentrations in ambient air are greater than the established Action Levels in the Policy.

- Stationary or portable continuous monitoring device(s) (e.g. Jerome meter or similar device)
- method detection limit of approximately 3 ppb, or less, if available
- sampling interval of approximately 10-15 minutes

The "Jerome meter" is a portable hydrogen sulfide meter manufactured by Arizona Instrument LLC, that has a detection range of 3 ppb to 50,000 ppb. The Jerome meter, or similar device, can be used as a portable or stationary continuous monitoring device with the use of the data logger. The number and location of continuous monitoring devices that are necessary for each landfill will be site specific. However, ideally, meter(s) should be located at the fence line (i.e. site assigned property line) of the property in the predominant downwind direction of the landfill, in low-lying areas, and in the direction of the nearest receptor(s) or in the area with the greatest number of odor complaints.

MassDEP recommends portable/stationary continuous monitoring field equipment rather than laboratory techniques that typically use integrated samplers (i.e. SUMMA canisters or Tedlar bags) for hydrogen sulfide ambient air monitoring. MassDEP recommends this type of monitoring for two reasons: 1) near continuous monitoring capability and 2) immediate sample results. The near continuous monitoring feature of field equipment can better account for the variability over time of hydrogen sulfide in ambient air. Additionally, time integrated samples cannot account for short-term spike concentrations. Continuous monitoring devices constantly sample and analyze gas concentrations over short intervals. Continuous monitoring devices can provide valuable insight into ambient air quality and can be used to measure the effectiveness (performance) of landfill gas control measures. Continuous monitoring devices can provide quantitative evidence of the effectiveness of response actions to address hydrogen sulfide and other landfill gas emissions. The reactivity of hydrogen sulfide also causes problems with time integrated samples. Hydrogen sulfide can react in the sample container with atmospheric gases and can result in the under-reporting of actual ambient air hydrogen sulfide concentrations.

Appendix C

Checklist for Hydrogen Sulfide and Odorous Landfill Gas Response Plans

Checklist for Hydrogen Sulfide and Odorous Landfill Gas Response Plans

The following checklist is presented to assist owner/operators in the preparation of a Hydrogen Sulfide and Odorous Landfill Gas Response Plan ("Plan"). The checklist identifies subject areas that should be addressed in a Plan for completeness. Depending upon site-specific conditions, some areas may require a more detailed discussion than others.

Task 1: Identify Potential Receptors

______ Identify Potential Receptors

______Review existing documents and/or conduct a survey to identify receptors and sensitive receptors (e.g. residential dwellings, health-care facilities, schools, day-care centers, senior centers or use centers) and their distances from landfill

______Develop an Odor Survey Plan (“Odor Loop”)

An odor survey plan identifies locations in the vicinity of the landfill that should be investigated to determine if odors or landfill gas emissions are present. The choice of locations should be based upon, but not limited to, the following: the proximity to the landfill, receptors, topography, meteorology, previous complaints, predominant wind direction, and other potential sources of odors and emissions.

Task 2: Develop procedures and protocols for logging the complaint

______ Establish phone line, fax line and contact person for complaints

______ Develop a complaint form

The complaint form should contain but not be limited to the following information: date of complaint, time of complaint, proximity to landfill, name, address and phone number of the caller, characterization of the odor, type and intensity of the odor, duration of the odor, and other comments by the caller (refer to Appendix E for the complaint form the MassDEP uses).

Task 3: Develop procedures for response to complaints

______ Identify OSHA health and safety plan procedures for investigating odor complaint

______ Develop field investigator data sheet (refer to Appendix E)

______ Establish procedures to identify source of odors

______ Identify remedial actions to be taken, if necessary

______ Provide recommendations to prevent reoccurrence of odors.

Task 4: Landfill Gas Monitoring Plan

______ Develop protocols for determining when the landfill gas monitoring plan for ambient air monitoring, near surface monitoring, landfill gas characterization, etc. should be implemented

______ Identify potential locations for hydrogen sulfide ambient air monitoring

______ Identify potential contractors, consultants, and vendors who provide landfill gas monitoring equipment and monitoring services, including but not limited to, ambient air monitoring

Task 5: Conceptual response actions in response to hydrogen sulfide or odors

______ Develop contingencies for potential problems

______ List technologies/response actions (refer to Appendix F)

______ Identify potential vendor/consultant who can implement such services

______ Identify implementation schedule including permitting

Task 6: Communication Plan

______ Describe how owner/operator will communicate information regarding: landfill complaints, public health advisories, assessment and monitoring activities and response actions to the general public and local health officials

Some examples of communication media are fact sheets, meetings, news releases, newsletters, web pages, faxes-on-demand, public notices, fliers etc.

APPENDIX D

Data Collection and Hydrogen Sulfide Exceedance Examples

Data Collection and Hydrogen Sulfide Exceedance Examples

As stated in Table I of the Policy, an exceedance of a hydrogen sulfide Action Level can occur in either of two ways:

(1) The average concentration of hydrogen sulfide measured at the point of compliance is greater than or equal to 15 ppb over an eight (8) hour averaging period; or,

(2) The average concentration of hydrogen sulfide measured at the point of compliance is greater than or equal to 30 ppb over a one (1) hour averaging period.

For both Action Levels, running averages are to be used in the determining any exceedance.

Table AL-1 on the following pages provides an example data set of hydrogen sulfide readings over a 16-hour period with calculations demonstrating an exceedance of the 15 ppb hydrogen sulfide concentration over an eight (8) hour period. The data set assumes that the hydrogen sulfide meter is newly installed so that there is no background information.

Column 1 is the Reading Number since the meter started operation.
Readings in this example are taken at 10-minute intervals. (6 readings per hour)

Column 2 is the recorded hydrogen sulfide reading in parts per billion (ppb) at 10-minute intervals.

Column 3 is the Reading Number taken 8 hours previously.

Column 4 is the recorded hydrogen sulfide reading taken 8 hours previously.

Column 5 is the cumulative 8-hour hydrogen sulfide reading.
Column 5 is calculated by adding the hydrogen sulfide readings for the previous 8 hours.
For a 10-minute sampling interval, 48 readings are taken over 8 hours.
In the example, the first 48 readings add to **432 ppb** (refer to reading 48 column 5).

To calculate the second running 8-hour period, the first reading is subtracted and the 49th reading is added. In the example, the first reading of **0** is subtracted; the 49^{th} reading of **18** is added (refer to reading 49 column 7).

To calculate the third running 8-hour period, the second reading is subtracted and the 50th reading is added. In the example, the second reading of **0** is subtracted and the 50^{th} reading of **22** is added (refer to reading 50 column 7).

Table AL-1 provides example calculations for readings 49 through 64
(refer to column 7).

Column 6 is the determination of whether there is an exceedance of the 15 ppb limit.

Note that 48 initial readings (6 per hour for 8 hours) are required to commence this calculation. Accordingly, determination of an exceedance begins with the 48th reading.

Note that, since an exceedance requires that the average hydrogen sulfide concentration be equal to or greater than 15 ppb over an 8-hour period, the cumulative hydrogen sulfide readings over the running 8-hour period must be greater than or equal to 720 ppm. (6 readings x 8 hours x 15 ppb = 720 ppb)

In the example, readings 80 through 92 each lead to an exceedance of the 15 ppb 8-hour running average. Although this example illustrates 13 calculated exceedances, any one exceedance would require a response action.

Column 7 provides example calculations for determining the cumulative running hydrogen sulfide concentration for readings 49 through 64.

Table AL-1

Data Collection and Exceedance Example for > 15 ppb in an 8 Hour Period

Page 1
Readings 1 through 32 (hour 0 through 6.3) (Readings taken every 10 minutes)

1 Reading Number	**2** H2S Level ppb	**3** 8-hour Previous Reading Number	**4** 8-hour Previous H2S Level	**5** 8-hour Running Total	**6** Limit Exceedance if >/=15 ppb	
1	0	-	-	0	-	
2	0	-	-	0	-	
3	0	-	-	0	-	
4	3	-	-	3	-	
5	3	-	-	6	-	
6	5	-	-	11	-	
7	3	-	-	14	-	
8	5	-	-	19	-	
9	7	-	-	26	-	
10	8	-	-	34	-	
11	10	-	-	44	-	
12	12	-	-	56	-	
13	17	-	-	73	-	
14	13	-	-	86	-	
15	19	-	-	105	-	
16	20	-	-	125	-	
17	17	-	-	142	-	
18	15	-	-	157	-	
19	13	-	-	170	-	
20	12	-	-	182	-	
21	12	-	-	194	-	
22	15	-	-	209	-	
23	16	-	-	225	-	
24	17	-	-	242	-	
25	15	-	-	257	-	
26	12	-	-	269	-	
27	10	-	-	279	-	
28	11	-	-	290	-	
29	8	-	-	298	-	
30	7	-	-	305	-	
31	7	-	-	312	-	
32	5	-	-	317	-	

Table AL-1

Data Collection and Exceedance Example for > 15 ppb in an 8 Hour Period

Page 2

Readings 33 through 64 (hour 6.3 through 12.6)

1 Reading Number	**2** H2S Level ppb	**3** 8-hour Previous Reading Number	**4** 8-hour Previous H2S Level	**5** 8-hour Running Total	**6** Limit Exceedance if >/=15 ppb	**7** Sample Calculations
33	3	-	-	320	-	
34	3	-	-	323	-	
35	3	-	-	326	-	
36	3	-	-	329	-	
37	3	-	-	332	-	
38	3	-	-	335	-	
39	4	-	-	339	-	
40	5	-	-	344	-	
41	6	-	-	350	-	
42	7	-	-	357	-	
43	8	-	-	365	-	
44	10	-	-	375	-	
45	12	-	-	387	-	
46	13	-	-	400	-	
47	15	-	-	415	-	
48	17	-	-	**432**	<15	
49	18	1	0	450	<15	**add 18, subtract 0**
50	22	2	0	472	<15	**add 22, subtract 0**
51	25	3	0	497	<15	add 25, subtract 0
52	23	4	3	517	<15	add 23, subtract 3
53	24	5	3	538	<15	add 24, subtract 3
54	27	6	5	560	<15	add 27, subtract 5
55	24	7	3	581	<15	add 24, subtract 3
56	22	8	5	598	<15	add 22, subtract 5
57	20	9	7	611	<15	add 20, subtract 7
58	19	10	8	622	<15	add 19, subtract 8
59	17	11	10	627	<15	add 17, subtract 10
60	16	12	12	631	<15	add 16, subtract 12
61	15	13	17	629	<15	add 15, subtract 17
62	15	14	13	631	<15	add 15, subtract 13
63	16	15	19	628	<15	add 16, subtract 19
64	17	16	20	625	<15	add 17, subtract 20

Table AL-1

Data Collection and Exceedance Example for > 15 ppb in an 8 Hour Period
Page 3
Readings 65 through 96 (hour 12.6 through 16)

1 Reading Number	**2** H2S Level ppb	**3** 8-hour Previous Reading Number	**4** 8-hour Previous H2S Level ppb	**5** 8-hour Running Total ppb	**6** Limit Exceedance if>/= 15 ppb	
65	19	17	17	627	<15	
66	19	18	15	631	<15	
67	20	19	13	638	<15	
68	21	20	12	647	<15	
69	23	21	12	658	<15	
70	21	22	15	664	<15	
71	17	23	16	665	<15	
72	18	24	17	666	<15	
73	19	25	15	670	<15	
74	17	26	12	675	<15	
75	16	27	10	681	<15	
76	16	28	11	686	<15	
77	16	29	8	694	<15	
78	17	30	7	704	<15	
79	17	31	7	714	<15	
80	16	32	5	725	**15.1**	**Exceeds Limit**
81	12	33	3	733	**15.3**	**Exceeds Limit**
82	8	34	3	738	**15.3**	**Exceeds Limit**
83	5	35	3	740	**15.4**	**Exceeds Limit**
84	3	36	3	740	**15.4**	**Exceeds Limit**
85	3	37	3	740	**15.4**	**Exceeds Limit**
86	3	38	3	740	**15.4**	**Exceeds Limit**
87	3	39	4	739	**15.4**	**Exceeds Limit**
88	4	40	5	738	**15.3**	**Exceeds Limit**
89	4	41	6	736	**15.3**	**Exceeds Limit**
90	5	42	7	734	**15.3**	**Exceeds Limit**
91	4	43	8	730	**15.2**	**Exceeds Limit**
92	4	44	10	724	**15.1**	**Exceeds Limit**
93	3	45	12	715	<15	
94	3	46	13	705	<15	
95	3	47	15	693	<15	

96	3	48	17	679	<15	

Data Collection and Exceedance Example for > 30 ppb in a 1 Hour Period

Table AL-2 on the following pages provides an example data set of hydrogen sulfide readings over a 12.6-hour period. Calculations are provided demonstrating two exceedances of the 30 ppb limit over a one (1) hour period. The data set assumes that the hydrogen sulfide meter is newly installed so that there is no background information.

Column 1 is the Reading Number since the meter started operation.
Readings in this example are taken at 10-minute intervals. (6 readings per hour)

Column 2 is the recorded hydrogen sulfide reading in parts per billion (ppb) at 10-minute intervals.

Column 3 is the Reading Number taken 1 hour previously.

Column 4 is the recorded hydrogen sulfide reading taken 1 hour previously.

Column 5 is the cumulative 1-hour hydrogen sulfide reading.
Column 5 is calculated by adding the hydrogen sulfide readings for the previous 1 hour.
For a 10-minute sampling interval, 6 readings are used per hour.
In the example, the first 6 readings add to **25 ppb** (refer to reading 6 column 5).

To calculate the second running 1-hour period, the first reading is subtracted and the 7th reading is added. In the example, the first reading of **4** is subtracted, the 7th reading of **3** is added (refer to reading 7 column 7).

To calculate the third running 1-hour period, the second Reading is subtracted and the 8th Reading is added. In the example, the second reading of **5** is subtracted, the 8th reading of **5** is added (refer to reading 8 column 7).

Table AL-2 provides example calculations for readings 7 through 15. (refer to column 7)

Column 6 is the determination of whether there is an exceedance of the 30 ppb limit.
Note that 6 initial readings (6 readings per hour for 1 hour) are required to commence this calculation. Accordingly, a determination of an exceedance begins with the 6th reading.

Note that, since an individual hydrogen sulfide concentration exceedance requires that the average hydrogen sulfide concentration be greater than or equal 30 ppb over a 1-hour averaging period, the cumulative hydrogen sulfide readings over the running 1-hour period must be greater than or equal 180 ppm.

(6 readings x 1 hours x 30 ppb = 180 ppb)

In the example, Reading Numbers 50 and 61 each lead to an exceedance of the 1-hour average of 30 ppb limit.

Note that, when Reading Number 50 resulted in an exceedance of the 30 ppb running average limit, the 1-hour running total in Column 5 was reset. The running total for Reading Number 51 (Column 5) is the same as Reading Number 51 (Column 2- **32 ppb**) and the running total of Reading Number 52 is the sum of Reading Numbers 51 and 52.

Column 7 provides example calculations for determining the cumulative running hydrogen sulfide concentrations for readings 7 through 15.

Table AL-2

Data Collection and Exceedance Example for > 30 ppb in a 1 Hour Period

Page 1

Reading Numbers 1 through 32 (hour 0 through 6.3) (Readings taken every 10 minutes)

1 Reading Number	**2** H2S Level ppb	**3** 1-hour Previous Reading Number	**4** 1-hour Previous H2S Level ppb	**5** 1-hour Running Total ppb	**6** Exceedance (1-hour running average >/=30 ppb)	**7** Sample Calculations
1	4	-	-	4	<30	
2	5	-	-	9	<30	
3	5	-	-	14	<30	
4	3	-	-	17	<30	
5	3	-	-	20	<30	
6	5	-	-	**25**	<30	
7	**3**	1	**4**	24	<30	**Add 3, subtract 4**
8	**5**	2	**5**	24	<30	**Add 5, subtract 5**
9	7	3	5	26	<30	Add 7, subtract 5
10	8	4	3	31	<30	Add 8, subtract 3
11	10	5	3	38	<30	Add 10, subtract 3
12	12	6	5	45	<30	Add 12, subtract 5
13	17	7	3	59	<30	Add 17, subtract 3
14	13	8	5	67	<30	Add 13, subtract 5
15	19	9	7	79	<30	Add 19, subtract 7
16	20	10	8	91	<30	
17	17	11	10	98	<30	
18	15	12	12	101	<30	
19	13	13	17	97	<30	
20	12	14	13	96	<30	
21	12	15	19	89	<30	
22	15	16	20	84	<30	
23	16	17	17	83	<30	
24	17	18	15	85	<30	
25	15	19	13	87	<30	
26	12	20	12	87	<30	
27	10	21	12	85	<30	
28	11	22	15	81	<30	
29	8	23	16	73	<30	
30	7	24	17	63	<30	
31	7	25	15	55	<30	

32	5	26	12	48	<30	

Table AL-2

Data Collection and Exceedance Example for > 30 ppb in a 1 Hour Period

Page 2

Reading Numbers 33 through 64 (hour 6.3 through 12.6)

1 Reading Number	**2** H2S Level ppb	**3** 1-hour Previous Reading Number	**4** 1-hour Previous H2S Level ppb	**5** 1-hour Running Total ppb	**6** Exceedance (1-hour running average >/= 30 ppb)	**7** Sample Calculations
33	7	27	10	45	<30	
34	9	28	11	43	<30	
35	9	29	8	44	<30	
36	13	30	7	50	<30	
37	14	31	7	57	<30	
38	17	32	5	69	<30	
39	20	33	7	82	<30	
40	20	34	9	93	<30	
41	19	35	9	103	<30	
42	23	36	13	113	<30	
43	27	37	14	126	<30	
44	29	38	17	138	<30	
45	32	39	20	150	<30	
46	33	40	20	163	<30	
47	29	41	19	173	<30	
48	27	42	23	177	<30	
49	29	43	27	179	<30	
50	32	44	29	**182**	**>30**	**Exceeds Limit**
51	**32**	45	---	**32**	<30	**Restart calculation**
52	25	46	---	57	<30	
53	25	47	---	82	<30	
54	23	48	---	105	<30	
55	24	49	---	129	<30	
56	22	50	---	151	<30	
57	27	51	32	146	<30	
58	32	52	25	153	<30	
59	32	53	25	160	<30	
60	33	54	23	170	<30	
61	37	55	24	**183**	>30	**Exceeds Limit**
62	32	56	22	32	<30	
63	27	57	27	59	<30	

64	26	58	32	85	<30	

APPENDIX E

Protocols for the Assessment of Off-site Landfill Odors

Protocols for the Assessment of Off-Site Landfill Odors

MassDEP will use a five (5) point odor intensity field reference scale as noted below:

0	Odor not detectable.
1 - Very Light	Odorant present in the air which activates the sense of smell, but the characteristics may not be distinguishable.
2 - Light	Odorant present in the air, which activates the sense of smell and is distinguishable and definite but not necessarily objectionable in short durations but may be objectionable in longer durations.
3. - Moderate	Odorant present in the air which easily activates the sense of smell, is very distinct and clearly distinguishable and may tend to be objectionable and/or irritating.
4 - Strong	Odorant present in the air, which would be objectionable and cause a person to attempt to avoid it completely.
5 - Very Strong	Odorant present which is so strong it is overpowering and intolerable for any length of time.

In general an odor nuisance shall be deemed to occur if the investigator determines that one of the following conditions exist:

1. The odor characteristic (or type of odor, separate from the intensity of the odor, example: rotten egg type or garbage odor) is deemed to be unpleasant or objectionable and the average odor intensity is determined by the inspector to constitute a level of three (3) or greater for a period of 15 minutes or greater. Odor "observations" shall be made at least twice during the 15-minute period and shall be noted in a logbook or form to be developed by MassDEP.

2. The odor characteristic (or type of odor, separate from the intensity of the odor, example: rotten egg type or garbage odor) is deemed to be unpleasant or objectionable and the odor intensity is determined by the inspector to constitute a level four (4) or greater for any period of time.

3. The odor characteristic (or type of odor, separate from the intensity of the odor, example: rotten egg type or garbage odor) is deemed to be unpleasant or objectionable and the odor intensity is determined by the inspector to constitute a level of two (2) or between levels two (2) and three (3) for a period of 60 minutes or greater. Odor "observations" shall be made at least three (3) times during the 60-minute period. MassDEP recognizes that the investigator will want to be able to continue with the odor survey. Therefore the investigator may leave the area in question as long as the investigator is present at the beginning and approximately the

end of the 60-minute period and also is present during some portion of the time in between. MassDEP may also consider the number of complaints received and the reported duration of the odor event when considering whether a "Level Two" odor would constitute a nuisance.

Note: Failure to act in accordance with these guidelines will not invalidate an odor nuisance determination made by an inspector.

Schedule of Odor Surveys

An Odor Survey Plan identifies locations in the vicinity of the landfill that personnel assigned to investigate the complaint shall visit and determine if odors are present. These locations shall be based upon, but not limited to, the following: the proximity to the landfill, receptors, topography, meteorology, predominate wind direction, accessibility and other potential sources of odors and emissions.

MassDEP will generally perform odor surveys of accessible off-site areas in the vicinity of a landfill under the following scenarios:

1) routine unannounced inspections - MassDEP will perform an odor survey.

2) scheduled inspections, tours, meetings on site - MassDEP will incorporate an odor survey if appropriate.

3) response to complaints - MassDEP will perform an odor survey.

MassDEP will generally respond to odor complaints under the following scenarios:

1) upon receipt of an odor complaint where the caller indicates that the odor is current and at a nuisance level and duration.

2) upon receipt of an odor complaint where the caller indicates that:
   - the odor was previously at a nuisance level and duration.
- a change in wind direction indicates the likelihood that nuisance conditions still exist at another off-site location.

MassDEP may not immediately perform a site inspection when complaints are received regarding previous odor conditions which are unlikely to exist at the time of complaint.

Site Specific Odor Survey Plan

For each landfill facility demonstrated or likely to be prone to producing off-site nuisance odors, a site-specific odor survey plan will be developed. Elements of each plan shall include but not be limited to the following:

Site Specific Odor Survey Field Data Log Sheet:

- date of survey
- start time of survey
- reason for survey: complaint response, periodic inspection, etc.
- atmospheric conditions: temperature, wind, current/previous precipitation, etc.
- routes/locations for odor surveillance
- time of survey at specified survey points
- odor intensity at specified survey points (1-5)
- odor description at specified survey points
- odor duration at specified survey points
- specific comments regarding odor source: solid waste facility, other facility, residential odors, etc.
- specific comments solicited from other persons

See Attachment A for sample log sheet.

Public Complaint Forms

MassDEP will also utilize standard forms for recording and investigating public odor complaints.

The Office Data Log Sheet recording the odor complaint will contain the following:

- date of complaint
- time of complaint
- solid waste facility proximate to the origin of complaint
- name, address, phone number of caller
- characteristic of odor as provided by the caller
    - intensity of odor (1-5)
    - duration of odor
- other comments by caller

See Attachment B for sample log sheet.

The Field data Log Sheet of MassDEP's investigation/evaluation of odor complaints will contain the following:

- date of complaint
- time of complaint
- solid waste facility proximate to the origin of complaint
- name, address, phone number of caller
- location where odor was detected
- characteristic of odor
- intensity of odor (1-5)
- duration of odor
- other comments by caller
- atmospheric conditions

See Attachment C for sample log sheet.

Sample
Attachment A
Site Specific Odor Survey Plan
INSERT LANDFILL NAME AND ADDRESS HERE **Sanitary Landfill**

Date ________
Weather____
Reason for Survey ______________________________________

Location	Time	Odor Intensity	Odor Type	Comments
Rte 495 at Overpass				
Rte 495 at Rte 1 exit				
Rte 1 at Entrance				
Rte 1 at truck stop				
Rte 1 at pond				
Rte 1 at Thurston St				
Thurston St at farm				
Thurston St at trail				
715 Thurston St				
Town Line at Woodside				
West St at Monitoring Wells				
94 West St				
78 West St				

Sample
Site Specific Odor Survey Plan cont'd
INSERT LANDFILL NAME AND ADDRESS HERE **Sanitary Landfill**

Location	Time	Odor Intensity	Odor Type	Comments
Daniels St at West St				
Daniels St at fence				
Campground at gate				
campground at tent area				
Spruce St at West St				
Spruce St at overpass				
Charles Samuel Way				
Mirimichi St at causeway				
152/106				
Taylor Road at spillway				

Comments: 1) ____
____
2) ____
____
3) ____

Attachment B

Odor Phone Log

Landfill ____

Date	Name	Address	Time	Scale 1-5 5 max	Phone	Comments

Attachment C
PUBLIC ODOR LOG FORM FOR LANDFILL ODORS

Today's Date:_______________

Name of Observer: ____
Address: ____
____

Landfill(s) in Proximity to Odor Observation ____________________

DESCRIPTION OF THE ODOR

1. what date was odor detected: ____________________
2. what time was odor first detected: ____________________
3. what time was odor last detected: ____________________
4. comments: ____
____

5. Where were you when you first smelled the odor?

Indoors at home? __________________
Were Windows Open? ______ Closed? ______
Outdoors at home? _______________
Other location (please specify) __________________________________

6. Strength of Odor: Intensity based on a scale of 1-5 _____
(see attached odor intensity scale)

7. Odor Character (type): ____________________________________
(rotten eggs, smoke, garbage, couldn't distinguish, etc)

8. Duration of Odor _________________________ Minutes Hours

METEOROLOGICAL CONDITIONS AT TIME OF ODOR OBSERVATION

1. Estimated Wind Speed ___________ MPH

2. Wind direction (FROM which wind is blowing)

_____ North _____Northeast ____ East _____ Southeast
_____ South _____Southwest ____ West _____ Northwest

3. Sky Conditions: % Cloud Cover _______
____ Rain ____ Overcast _____ Snow

Form Completed By: ____________________________ Date: _________

Form Received By: ____

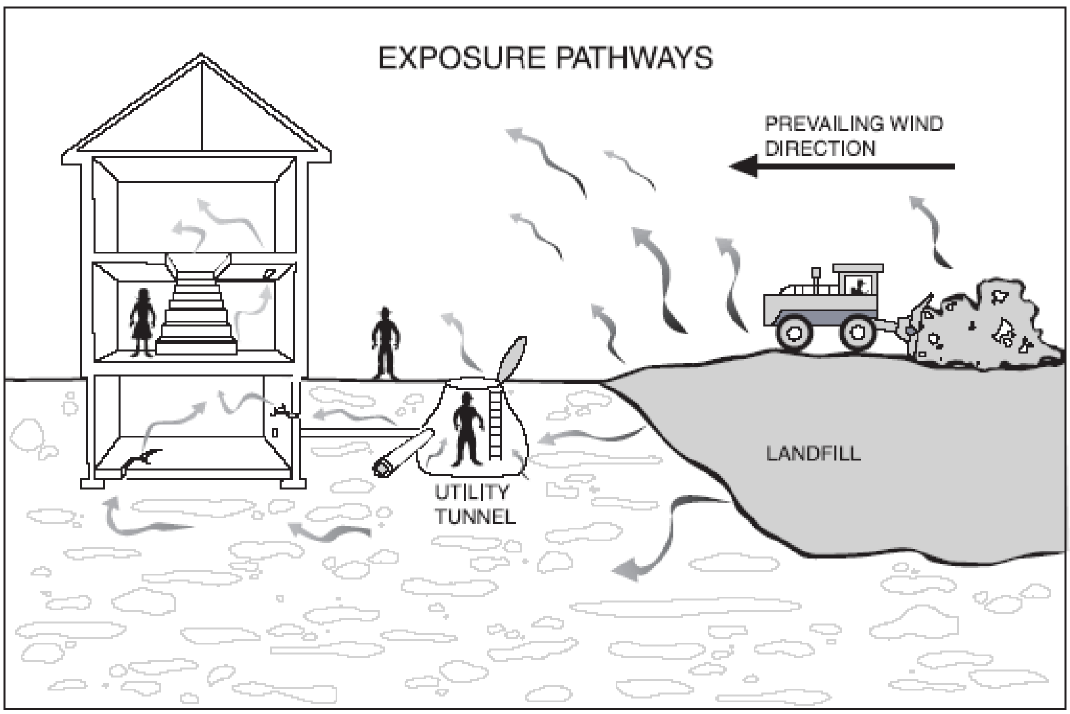
APPENDIX F

HEALTH AND SAFETY ISSUES ASSOCIATED WITH HYDROGEN SULFIDE

Health, Safety & Welfare (Nuisance) Issues Associated with Hydrogen Sulfide and Odorous Landfill Gas

This appendix provides basic information about health and safety issues associated with hydrogen sulfide and odorous landfill gas. People may be exposed to landfill gasses, including hydrogen sulfide, at the landfill and/or off-site. Exposures only occur if the landfill is producing landfill gas/hydrogen sulfide and only if the gasses are migrating from the landfill. Landfill gasses can migrate from a landfill below ground, within soils, or above ground in the ambient air.

Potential Exposure Pathways to Landfill Gas



Source: ATSDR 2001

I. Health Impacts

Many of the compounds detected in landfill gas can be a health concern if present at elevated concentrations. This section focuses only on air quality impacts and risk to public health through the release of hydrogen sulfide to ambient air. Breathing hydrogen sulfide at concentrations greater than 500 ppm can be fatal within a few breaths. At concentrations above 100 ppm, a person may not be able to smell hydrogen sulfide. Since a person's sense of smell becomes rapidly fatigued, the sense of smell cannot be counted on to warn against the continued presence of the gas.

At lower concentrations hydrogen sulfide causes health symptoms from inhalation that may include: throat irritation, bronchial constriction, inflammation of the nasal membranes, compromised lung function, headache, nausea and central nervous system effects. The effects of hydrogen sulfide are even more pronounced on sensitive individuals including asthmatics and others with lung function deficiencies, persons with ulcerative colitis (these persons cannot detoxify hydrogen sulfide in the digestive tract), and persons with cardiac and neurological disorders. While hydrogen sulfide has not been shown to cause cancer in humans, EPA has not classified it regarding its ability to cause or not cause cancer (ATSDR, July 1999).

II. Public Safety

Explosion Hazards

In order for landfill gas to pose a potential explosion hazard, the waste within the landfill must be producing gas containing chemicals that are present at explosive levels.

Hydrogen sulfide is unlikely to be present at concentrations high enough to pose an explosion hazard. The Lower Explosive Limit ("LEL") for hydrogen sulfide is 4.3 percent by volume or 43,000 ppm and the Upper Explosive Limit ("UEL") is forty-five (45) percent by volume (450,000 ppm). The principal explosive component of concern in landfill gas is methane. Methane is explosive between its LEL of five (5) percent (50,000 ppm) by volume and its UEL of fifteen (15) percent (150,000 ppm) by volume. The UEL is the maximum concentration of gas or vapor above which a substance will not burn when exposed to an ignition source. This does not mean the concentrations above fifteen (15) percent methane are not of concern. As methane migrates (through soils or ambient air) and is diluted by atmospheric gasses, the resultant mixture can be quickly lowered to within the explosive range of methane. Other landfill gas constituents like ammonia, hydrogen, and volatile organic compounds are flammable but are unlikely to be present at concentrations above their LEL.

Asphyxiation Hazards

Landfill gas can pose an asphyxiation hazard if it collects in a confined space (e.g. landfill gas collection system, leachate collection systems, basements, manholes, utility conduits and structures). Either individually or in combination, landfill gasses can create an asphyxiation hazard if they are present at concentrations sufficient to create an oxygen deficient atmosphere. The two major components of landfill gas, methane and carbon dioxide, are asphyxiants. Hydrogen Sulfide is also an asphyxiant but is usually detected at trace concentrations (less than 1 percent). An oxygen deficient environment is defined by the Occupational Safety and Health Administration (OSHA) as one that has less than nineteen and one-half (19.5) percent oxygen by volume. Ambient air contains approximately twenty-one (21) percent oxygen by volume.

Landfill Fires

Landfill fires may or may not be directly caused by landfill gas. However, landfill fires may pose a potential risk to public health and safety due to gasses released and particulates associated with the fire. It is very important to properly manage (balance) active landfill gas control systems in order to avoid applying too high a vacuum to the active landfill gas control system. Applying too much vacuum can result in introduction of oxygen into the solid waste mass, which increases the risk of fire (refer to Appendix B and the Manual). Once a landfill fire begins it can be extremely difficult to extinguish.

III. Public Welfare (Nuisance)

Even when concentrations of hydrogen sulfide do not pose a risk to public health they may pose a risk to public welfare by creating a nuisance odor. Odors can have an undesirable effect on quality of life. Sometimes odors associated with hydrogen sulfide may be sufficient to make people feel ill but it should be kept in mind that such illness is a reaction to the odor and should improve once the odor dissipates. Also, residents located in the vicinity of landfills have reported being woken up due to landfill gas odors in their homes. Of further note, there is some evidence that odors in and of themselves may trigger respiratory effects among asthmatics (ATSDR 1999b).

> "*At low concentrations* (of hydrogen sulfide) -*typically associated with landfill gas-it is unclear whether it is the constituent itself or it is the odors that trigger a response. Typically, these effects fade when the odor can no longer be detected*" (ATSDR, 2001).

The sense of smell, just like the other senses, varies from person to person. Due to this variation, what is deemed a nuisance odor varies among the population. MassDEP has noted this variation among MassDEP staff and persons filing odor complaints with MassDEP. To reduce the subjectivity of odor evaluation some MassDEP staff have been trained to objectively evaluate odors (refer to St. Croix Sensory, Inc., 1997). MassDEP's approach when investigating odor complaints involves: 1. characterizing the odor (what does it smell like?); 2. determining the intensity of the odor (how strong is it?); and, 3. determining the duration of the odor (how long has it persisted?). Based on these factors, MassDEP determines if an odor nuisance condition exists offsite (refer to MassDEP's Odor Protocol, Appendix E).

A level of no significant risk of harm to public welfare exists, or has been achieved, if no nuisance conditions exist in the breathing zone of ambient air and indoor air and the air will, in the reasonably foreseeable future, remain free from persistent, noxious odors (310 CMR 40.0994).

A landfill's day-to-day operations can create nuisance levels of odors from time to time. However it is the presence of "persistent" or frequent odors that result in risk to public welfare (nuisance).

IV. Worker Protection Standards for Hydrogen Sulfide

The Occupational Safety and Health Administration (OSHA), the National Institute for Occupational Safety and Health (NIOSH) and the American Conference of Governmental Industrial Hygienists (ACGIH) develop standards (OSHA) and guidance (NIOSH and ACGIH) for hazardous substances or conditions in the workplace. These numerical limits tend to be in the parts per million (ppm) range for H_2S. Their current guidance for workers can be found on their respective websites which may include both ceiling limit values and concentrations which would be associated with potential for immediate death or serious impairment:

- OSHA: http://www.osha.gov/SLTC/pel/index.html
- NIOSH: http://www.cdc.gov/niosh/idlh/intridl4.html
- ACGIH: http://acgih.org/home.htm

OSHA regulations require employers to furnish a place of employment that is free of recognized hazards that cause or are likely to cause death or serious physical harm to employees. Employers have the obligation to eliminate recognized hazards, provide necessary levels of worker training, provide appropriate safety gear, develop a spill or hazard response plan, and/or perform a risk assessment. Additional information regarding worker health and safety protection requirements can be found on the agencies respective websites.

V. Hydrogen Sulfide Exposure Limits and Exposure Criteria for the General Public

Hydrogen sulfide health-based exposure limits for ambient air are generally lower (parts per billion, ppb, range) than the short-term worker protection standards referenced above. This is largely due to the fact that many of the exposure limits and exposure criteria for the general public are designed to be protective of sensitive individuals. In contrast, the OSHA/NIOSH/ACGIH short-term standards are designed to protect workers. Workers are generally healthy adults, typically between the ages of 18 and 65 who are exposed on average for forty hours per week. The general public is more heterogeneous, including children, the elderly and individuals with a wide range of health concerns. Exposures to the general public may also be continuous. Additionally, technical feasibility and costs associated with achieving standards are typically considered when developing an occupational standard, whereas other standards may have not considered these factors when developing a health-based value for the general public.

The following organizations provide guidance for either short or longer-term H_2S exposures and should be consulted for their latest guidance values:

- U.S. Environmental Protection Agency (www.epa.gov)
  - Chronic inhalation reference concentrations (RfCs) (www.epa.gov/iris/
  - Acute exposure guideline levels (AEGLs) (http://www.epa.gov/opptintr/aegl/index.htm);

- Agency for Toxic Substances and Disease Registry
  - Minimal risk levels (MRLs, for acute and intermediate duration exposures) (http://www.atsdr.cdc.gov/mrls.html);

- California Office of Environmental Health Hazard Assessment
  - Acute reference exposure levels (RELs) (http://www.oehha.org/air/acute_rels/allAcRELs.html).

The Massachusetts Department of Environmental Protection provides chronic exposure limits for H_2S in the form of a Threshold Effect Exposure Limit (TEL) and an Allowable Ambient Limit. These values are intended to protect against the possibility of either threshold or non-threshold (cancer) effects from chemicals as a result of long-term exposures. When a chemical has no known or anticipated non-threshold effects, the AAL and the TEL values are equivalent as is the case with H_2S. The TEL is compared to 24 hour average concentrations as a check against shorter-term spikes in concentrations. The AAL value is compared to annual average concentrations. The present TEL/AAL is 1 ug/m^3 (0.7 ppb). MassDEP is presently identifying appropriate short-term exposure limits for H_2S.

APPENDIX G

Landfill Gas Control Technologies

Landfill Gas Control Technologies

This section presents an overview of landfill gas control technologies. Landfill gas control systems are designed to control air pollution (limit emissions of greenhouse or harmful gasses, prevent nuisance odor conditions), control the migration of explosive gasses and to protect the landfill cover system by preventing uplift damage to a geomembrane cap or impacts to the vegetative layer. Landfill gas can be managed by either a passive or an active gas control system. Active systems use vacuums or blowers to move gas through a collection system (connected by header lines) by maintaining low-pressure within the collection system wells and/or horizontal collection trenches. Passive and active landfill gas control systems convey landfill gas through the collection system for discharge to ambient air. Passive systems may or may not include treatment technologies prior to discharge to ambient air. Active systems typically require treatment of the landfill gas to comply with air quality regulations. Treatment typically consists of combustion (e.g. flare, turbine) or non-combustion technologies (e.g. carbon canisters). The control technologies discussed herein can be implemented separately or in combination with each other. The design of a landfill gas control system will be site-specific.

The MassDEP does not currently mandate that all landfills have landfill gas control systems installed during active operations. However, the MassDEP strongly recommends that landfill gas control systems be installed and operated during active landfilling. By installing the gas control system as the landfill is filled, the system can be quickly retrofit with a solar flare or to an active system, if the landfill generates nuisance odor conditions prior to final grades being reached.

General Design Considerations. Design of a gas control system should consider factors such as; landfill gas composition, the location of the site relative to residences (receptors), nuisance odor problems associated with the landfill, the depth to groundwater, the dimension of the landfill mass, the age of the landfill waste, geology of the site, soil transmissivity and the potential for gas migration from the site.

An active landfill gas extraction, collection and treatment system is the preferred technology to control landfill gas emissions or migration. When there is an increased risk of landfill gas migration to buildings, passive control systems are usually inadequate to ensure protection of public safety.

Soil gas monitoring networks are the best way to ensure the landfill gas extraction and collection systems are performing properly. Landfill gas monitoring programs are intended to detect the presence and migration of landfill gasses in order to ensure that landfill gas concentrations do not:

- **exceed 10 percent of the Lower Explosive Limit (LEL) in any building, structure, or underground utility conduit (excluding gas**

control, gas recovery, or leachate collection systems components); or

- **exceed 25% of the LEL at the property boundary or beyond (310 CMR 19.132(4)(g)&(h))**

The efficiency of a gas control system depends in large part on how effectively the landfill gas is being collected from within the landfill waste mass. In most cases, landfill waste is not homogeneous, which complicates the collection system design. The presence of a low permeability barrier (intermediate cover or final cover system) over the Landfill will prevent landfill gas from escaping to ambient air and ensure that landfill gas flows into the gas collection system. If the landfill was constructed with a base liner, the landfill gas collection system will be more efficient, since the liner will prevent landfill gas from migrating laterally away from the landfill.

It is also important to consider when designing and operating an active gas system the potential to draw in outside oxygen into the system which could cause a fire within the landfill mass. Landfill fires are very difficult to locate and extinguish and may damage the base liner and/or final cover system.

Another factor to consider in gas control system design is how much methane the landfill is generating. In some cases, MassDEP has experienced low methane production accompanied by very high hydrogen sulfide production. The low methane production is a problem since the preferred, and most effective, treatment technologies for controlling landfill gas and hydrogen sulfide are combustion technologies. Combustion technologies such as flares require sufficient fuel (methane) in order to treat the hydrogen sulfide. Therefore, any corrective action requiring combustion should consider methane production in addition to hydrogen sulfide emissions at the landfill and determine the need for a supplemental fuel supply. At several landfills, passive and active gas collection systems were designed to address areas of the landfill that were producing high concentrations of hydrogen sulfide. Supplemental fuels such as propane or natural gas, if available, may be necessary to maintain combustion.

The preparation and implementation of an operation and maintenance plan for the gas control system is a key factor to ensure effective control of landfill gas emissions and soil gas migration. The operation and maintenance of the landfill gas control system requires expertise with the control system and monitoring equipment and should not be attempted by individuals who do not have proper training.

Cover materials. The application of additional compacted soils to the landfill surface is one of the first corrective actions that a landfill operator can take to reduce odors emanating through the landfill surface but rarely provides a long-term solution. Landfill gas can be temporarily contained within the landfill using intermediate cover material (soil with a maximum permeability of 1×10^{-5} cm/sec) and through the application of flexible membrane liners. This will temporarily reduce emissions to the atmosphere by providing a barrier to gas migration through the landfill surface. The application of soils or other barrier layers will provide time to allow more comprehensive corrective actions to be designed and implemented. Any improvement in air quality due to the application of soils is temporary unless combined with a passive or active gas collection system. If soils are applied alone, internal landfill gas pressure gradients increase, which can result in landfill gas migrating laterally or building up sufficient pressure to cause breakouts (e.g. fractures or openings in cover materials) through the overlying surface of the landfill. These breakouts are often visible by the dark (e.g. black, gray) stained cover materials in the vicinity of the breakout. This is a primary reason why the application of low permeability soils or flexible membrane liners in combination with active gas controls and treatment is the most effective method for controlling landfill gas emissions and landfill gas migration.

Alternative daily cover materials, such as "Posi-shell", are encouraged due to the improved sealing of the landfill surface, preventing infiltration of precipitation and exfiltration of landfill gasses.

Passive Gas Control Systems

Passive landfill gas control systems rely on gas diffusion and convection processes caused by pressure gradients between gas contained within the landfill and ambient air. In the absence of odors or landfill gas migration, passive gas collection systems are commonly installed during placement of final cover (capping). Passive control systems installed during closure typically use vent wells which are installed vertically through the landfill mass (75 percent of the depth of waste for lined landfills) prior to final closure. The installation of vertical gas collection wells requires specialty-drilling equipment such as bucket augurs or powerful drilling rigs.

When installed, a passive control system shall be designed so it can be retrofitted to an active gas control system. In addition to vertical gas collection wells, horizontal collection systems can also be installed within the footprint of the landfill waste mass. Horizontal gas collection systems include excavation of landfill waste and installation of slotted piping within a trench. The trenches are backfilled with permeable materials such as gravel.

Passive gas control systems using horizontal gas collection systems are often installed during active operations to prevent odors emanating from the landfill. They are often the first type of gas collection system to be installed in response to odors emanating from the active area of a landfill. They can be constructed as layers of waste are landfilled. Horizontal gas collection systems can be installed with a backhoe and don't require the specialty equipment (e.g. bucket augurs or drill rigs) that is required for vertical gas collection wells.

Passive venting systems using vertical or horizontal gas collection wells can also be used to control landfill gas migration. Trenches constructed around the perimeter of the landfill are filled with permeable materials such as gravel that intercept the migrating gas and vent it to the atmosphere. Alternatively, the collected gas can be connected to an active gas collection system.

Other technologies to address gas migration include barrier systems constructed between the perimeter of the landfill and the receptor. However, they tend to be more costly than vertical or horizontal gas control systems. The barrier systems should extend to a low permeability soil layer, natural bedrock or groundwater. It should be noted that bedrock is not always an effective barrier to landfill gas migration should the bedrock be fractured. It is not uncommon to use a combination of technologies to address landfill gas migration problem.

Active Gas Control Systems

Where passive landfill gas control systems are deemed ineffective, active gas systems need to be used to collect and treat landfill gas. Active gas systems remove landfill gases from the landfill by creating a vacuum, which induces gas flow from the gas collection system through header lines to, in most cases, a flare. A gas flare will treat methane and non-methane organic compounds (NMOCs), and reduce odors.

Active landfill gas control systems require routine balancing of the well field to ensure proper operations. Systems need to be routinely inspected for settlement and leaks. Extraction wells need to be checked routinely for leachate/condensate buildup. Header lines need to be checked for condensate buildup that may inhibit the flow of landfill gas. Failure to properly maintain and operate a passive or active gas control system can result in a point discharge to ambient air or lead to the onset of odors and landfill gas migration due to poor collection efficiencies.

The best header line design for an active gas control system is considered the "loop design" with integrated shutout valves spaced throughout the header system. The loop design allows for the active system to operate efficiently should the header line become clogged in some location and that section needs to be isolated and shut down for repair.

An active gas control system can be used to fuel a gas to energy facility, such as an internal combustion engine. This type of system provides several advantages for the operator including: environmental control of gas emissions and odors, conservation of natural resources through use of gas as a fuel to generate electricity, a positive community image, and an economic return.

The major components of an active gas control system include:

- Vertical gas collection wells,
- Horizontal gas collection systems,
- Gas collection header lines;
- Blower,
- Condensate collection system,
- Gas treatment system.

Vertical Gas Collection Well Design

Vertical gas collection wells are used in the interior of the landfill or around the perimeter of the waste to provide a conduit for the collection and control of landfill gas. The installation of vertical landfill gas collection wells can result in odors during drilling.

The MassDEP recommends the use of an "odor box" when installing landfill gas wells. This odor box is a device that captures landfill gas and conveys the gas to an attached flare or can be connected to an active gas extraction system if available. An odor box can also be used to control worker exposure to landfill gas.

Vertical gas collection well design should consider the following criteria:

- For unlined landfills: drilling to the water table or the base of the waste, whichever is less;
- For lined landfills: drilling to approximately 75% of the depth of the waste to avoid damage to the liner;
- Wells should be adequately spaced to vent all portions of the landfill. Every 200 feet is typical. The exact spacing will depend on whether the system is passive or active and site-specific criteria such as depth of waste, types of waste, distance to receptors, current and future gas generation, and landfill gas control technology chosen. Tighter gas well spacing may be appropriate based upon site-specific criteria. For landfills with active gas control systems that do not have odors or landfill gas migration issues, a 200-foot spacing between extraction wells is recommended. Tighter well spacing is recommended for landfills that have odors or subsurface soil gas migration.
- Wells should be designed to be suitable for an active gas control system,
- Wells should be screened for the entire depth of the well, except for a portion of the top where solid pipe should be used to prevent ambient air from being drawn into the well;
- Boreholes should be backfilled with permeable gravel;
- Wells should be properly sealed, particularly in an active system, to keep ambient air from being drawn into the well;
- Wells should be equipped with sampling ports to enable easy sampling of the gas from the well.
- Wells should be constructed with large diameter boreholes (36 inch) in order to achieve sufficient radius of influence for gas extraction wells at 200 ft. spacing (For more detailed design information refer to the Manual).

1 Pretreatment

Pretreatment of landfill gas is sometimes required prior to combustion. For example, scrubbing systems are often required to minimize emissions of hydrogen sulfide and sulfur dioxide from flares or other landfill gas combustion equipment. Generally, landfill gas containing concentrations of hydrogen sulfide greater than 200 ppm require pretreatment.

Dry scrubbers. Dry scrubber systems generally use some type of containerized media that reacts with specific compounds in landfill gas, such as hydrogen sulfide, and forms solid compound that can then be disposed of. (Also see Sulfur Treatment Systems below).

Wet Scrubbers. In wet scrubber systems landfill gas comes into contact with a slurry that chemically reacts with and removes the target compound from the landfill gas.

All pretreatment systems are sensitive to the amount of reactive material available for the chemical reaction to occur. As the available reactive media is depleted the effectiveness of the system is reduced, often requiring multiple units to ensure the targeted level of treatment is obtained.

Combustion Technologies

Combustion is the most common technique for controlling and treating landfill gas. Combustion technologies such as flares, gas turbines and internal combustion engines thermally treat the compounds in landfill gas. Combustion technologies are most efficient when the landfill gas contains at least 20 percent methane by volume. At this concentration, the landfill gas will readily form a combustible mixture with ambient air, so only an ignition source is needed for operation. At landfills with less than 20 percent methane by volume, supplemental fuel (e.g. natural gas, propane) is required to operate the flare, this increases operating costs dramatically. Propane does not burn as hot as methane and its use may reduce the flare's efficiency in destroying, for example, hydrogen sulfide and result in odorous emissions from the flare to the ambient air.

Open Flame Flares. Open flame flares, sometimes referred to as vent flares, solar flares or candlestick flares, offer a means to thermally treat landfill gas with or without an active gas collection system. Vent flares can be effective in addressing landfill gas emissions when an active gas control system is not in place. Vents flares are typically bought as a complete package and can be installed and delivered quickly to the site. They are often used as an interim treatment technology while active gas control systems are being designed, permitted and installed. Vent flares are specifically designed to be mounted on top of existing passive vertical gas collection wells or wellheads. The number of vent flares will depend on design of the passive gas collection system and the landfill gas flow rates. The units are self-contained and operate using a solar collector to recharge a battery that supplies the ignition source. Supplemental fuel can be supplied to these types of flares, however the use of propane, as stated previously, can lead to incomplete combustion of hydrogen sulfide and result in odors emanating from the flare.

Depending on particular models, these vent flares can operate over a flow rate range of 2-100 cubic feet per minute. Approximately 30 percent to 80 percent equivalent methane concentration (combustible gases) is necessary over this flow rate range. Destruction efficiencies for methane and hydrogen sulfide of greater than 99 percent are possible with up to 98 percent NMOC reductions, if the flares are operated in accordance with manufacturers specifications. Changes in barometric pressure and pressure gradients within the landfill can result in a reduction of landfill gas reaching the vent flare. This can result in flame out of the flare. The vent flares typically have an automatic re-ignition process, however, the flare may not reignite if methane content is insufficient to support combustion. This can result in untreated landfill gas emissions to ambient air from the vent flares. To prevent flameouts, supplemental fuel may need to be added to assist in combustion. Additionally, regular inspection of the vent flares is important. An Operation and Maintenance Plan should be developed to address vent flare operations and be submitted with any request to use vent flares. The MassDEP has noted a strong correlation with odor complaints resulting from poor vent flare operation and maintenance.

In addition to vent flares that are designed to operate at relatively low landfill gas flow rates, there are larger open flares (candlestick flares, typically skid mounted) that can operate at much higher landfill gas flow rates. These large open flares are usually permitted and used as a temporary solution until a permanent, more efficient enclosed flare is properly permitted. These larger open flares require active landfill gas collection systems in order to maintain flow rates sufficient for operation. The simplicity of the design and operation of an open flame flare is one of its advantages. Disadvantages include combustion efficiency, aesthetic complaints, and difficulties associated with monitoring combustion parameters compared to enclosed flares. These candlestick flares typically include the following design features:

- Automatic shutdown system when the percentage of gas moves beyond set low or high limits,
- Flame suppresser,
- Automatic restart where the flame is blown out,
- Automatic shutdown of the fans when restart does not occur after three tries,
- Alternative source of fuel for startup of the flare.

Enclosed Flame Flares. Enclosed flame flares are more complex and expensive than open flame flares. Enclosed flame flares consist of multiple burners enclosed within fire resistant walls that extend above the flame. Unlike open flares, the amount of gas and air entering an enclosed flame flare can be controlled making combustion more reliable and more efficient. Enclosed flame flares are also easier to monitor.

Other Enclosed Combustion Technologies. Boilers, heaters, gas turbines and internal combustion engines are also used to treat landfill gas and can be used to generate energy or electricity.

Non-Combustion Technologies

In addition to combustion technologies there are chemical and biological technologies, which neutralize, oxidize, react or bind with odor causing compounds to treat the landfill gas. The effectiveness of these technologies is primarily dependent on the flow rate, chemical composition and chemical concentration of the landfill gas. These systems typically require an active program of monitoring and maintenance to add chemicals or replace depleted media as needed. The specific examples of non-combustion technologies listed herein have been used to control odors at Massachusetts's facilities. There are many other chemical and biological technologies that are not discussed in this document.

Carbon Canisters. Carbon canisters are designed to absorb hydrogen sulfide and volatile organic compounds onto a carbon media. Carbon canisters are typically used with passive systems and are installed on individual vertical landfill gas collection wells. Carbon canisters are often used as a temporary measure until more comprehensive corrective actions can be implemented. One problem with carbon canisters is they often need frequent replacement due to media saturation. The time duration the carbon canisters remain effective is dependent on the landfill gas flow rate and on the concentration of hydrogen sulfide and other compounds in the landfill gas.

Sulfur Treatment Systems. Sulfur treatment systems use an iron compound coated onto ceramic media to treat hydrogen sulfide. These systems include various size vessels filled with the iron compound. These systems have been used for hydrogen sulfide pretreatment in conjunction with flares to reduce hydrogen sulfide concentrations in the landfill gas prior to the gas being treated at the flare, thereby reducing hydrogen sulfide and sulfur dioxide emissions from the flare to the ambient air.

Biofiltration. Biofiltration is a biological process that oxidizes the volatile organic compounds ("VOCs") into carbon dioxide and water. In the case of compounds containing sulfur, nitrogen or chlorine, the oxidation products are mineral salts. The primary interest in biofiltration today is for odor control or to reduce hazardous air pollutants ("HAPs") for regulatory compliance. The technology is usually applied to gas streams with large volumetric flow rates and with dilute HAP concentrations, typically 1,500 ppm or less, but sometimes as high as 5000 ppm. The technology is proven and cost effective, but suitability is dependent on the pollutant. The technology has been successfully installed by composting facilities, wastewater treatment facilities, rendering facilities and spray booths.

Masking Agents. Masking agents are used at many landfills to alleviate objectionable odor nuisance conditions off-site, due to odorous materials being disposed and/or when performing odor producing activities, such as the excavation of waste during installation of gas collection systems. Masking agents do not chemically alter the odorous molecule. Masking agents are designed to mimic natural, pleasant odors that are not generally deemed offensive. Masking agents do not treat or reduce the concentrations of odorous compounds in the landfill gas and will not mitigate any risk to public health and safety.

For additional information regarding landfill gas control technologies refer to MassDEP's regulations 310 CMR 19.000, the MassDEP's Landfill Technical Guidance Manual and EPA's web page (www.epa.gov).

APPENDIX H

FREQUENTLY ASKED QUESTIONS

Frequently Asked Questions

1. How will the MassDEP implement this policy?

The Hydrogen Sulfide and Odorous Landfill Gas Response Plan (Plan) is the major tool MassDEP will use to implement this guidance. As specified in the Applicability section, certain landfills will need to develop a Plan. MassDEP will review that plan as part of the permitting process for new or expanding landfills or those developing a closure plan. The Plan will establish how a facility will respond to either an odor problem or an H_2S problem. The Plan should lay out what steps a facility owner/operator will take to verify that there is a problem, assess the problem and respond to and solve the problem. The Guidance provides the framework that should be used in the development of a Plan. The steps provided in the Guidance are intended to be a series of progressive steps that will be undertaken until a problem is solved.

2. Which landfills are required to develop a Hydrogen Sulfide and Odorous Landfill Gas Response Plan?

All landfills accepting solid waste that have historically or are currently generating landfill gas that is causing odors off-site will be required to prepare a Plan that complies with the MassDEP's new Policy requirements. This includes unlined landfill closure projects that accept construction and demolition debris fines/residuals in accordance with "*Revised Guidelines for Determining Closure Activities at Inactive Unlined Landfill Sites*", revised July 2001.

2. When will new and existing active landfills be required to develop a Hydrogen Sulfide and Odorous Landfill Gas Response Plan?

All new landfills will be required to submit a Plan as part of their Authorization to Operate permit application. The requirements will not be retroactive for existing landfills that have not had historic odor problems. To continue current operations, however, any existing active landfill will be required to submit a Plan when applying for a permit for expansion or for renewal of an existing operating permit.

Additionally, MassDEP reserves the right to require that the landfill owner/operator of any existing landfill prepare a Plan and/or install hydrogen sulfide monitoring devices during operations as necessary to maintain the environment free from objectionable nuisance conditions, potential dangers or threats to public health, safety or the environment. A BWP SW 22, minor permit modification application, for the facility Authorization to Operate permit will be required.

3. Which landfills are exempt from preparing a Hydrogen Sulfide and Odorous Landfill Gas Response Plan?

The requirement for developing a Plan does not apply to Landfills that accept only ash or soils or other materials that do not have the potential to generate landfill gases.

4. Which landfills must have a Hydrogen Sulfide and Odorous Landfill Gas Response Plan in place and have hydrogen sulfide monitoring devices in place as part of operations?

Unlined landfill closure projects that accept construction and demolition debris fines/residuals in accordance with "*Revised Guidelines for Determining Closure Activities at Inactive Unlined Landfill Sites*", revised July 2001, will be required to have a Plan and be required to conduct hydrogen sulfide monitoring during closure activities. Additionally, if landfill gas monitoring demonstrates that hydrogen sulfide is creating a nuisance odor condition off-site, the landfill owner/operator will be required to prepare a Plan for the specific facility and install hydrogen sulfide monitoring devices.

5. When is an Odor Action Level Investigation & Response Action Required?

Often, increased landfill gas emissions at landfills are accompanied by associated odors and result in complaints to the landfill owners/operators, local officials and/or MassDEP**.** Odor Action Level investigations and appropriate response actions are required upon the receipt of a complaint or detection of odors off-site or presence of odors at nuisance levels off-site. In addition to off-site odors, landfill personnel should be cognizant of odors that exist on-site that have sufficient intensity to potentially migrate off-site. Therefore, landfill owners/operators should take all necessary actions as soon as possible once they detect an on-site odor even before a complaint from an abutter can be placed.

Note**:** A nuisance odor is defined by the odor characteristics (type of odor), intensity and duration.

6. When is a Hydrogen Sulfide Action Level Investigation and Response Action Required?

Hydrogen Sulfide response actions are required when there is an exceedance of the Hydrogen Sulfide Action Level, which occurs when either of the following occur:

- Hydrogen sulfide concentrations exceed 15 ppb averaged over an 8 hour period; or,
- Hydrogen sulfide concentrations exceed 30 ppb averaged over a 1-hour period.

Note: For Sample calculations for Action Level Exceedances refer to Appendix D.