



Environmental Protection Agency  
Office of Environmental Enforcement (OEE)

**Air Guidance Note 6 (AG6)  
Surface VOC Emissions Monitoring on  
Landfill Facilities**

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Wexford, Ireland.

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## Preface

The Office of Environmental Enforcement (OEE) is one of the five offices of the Environmental Protection Agency (EPA). The OEE's functions include the regulation of activities licensed under the EPA and Waste Management Acts. It is the policy of the OEE to provide information and advice via published guidance to those it regulates in order to secure environmental improvements while ensuring value for money.

This *Surface VOC Emissions Monitoring on Landfill Facilities* Guidance Note 6 (AG6) is one of a series of guidance notes that the OEE has planned on the general theme of air pollution monitoring and assessment.

Forerunners in this document series are:

Air Guidance Note 1: Guidance Note on Site Safety Requirements for Air Emission Monitoring (AG1)

Air Guidance Note 2: Air Emissions Monitoring - Guidance Note #2 (AG2)

Air Guidance Note 3: Air Guidance Note on the Implementation of I.S. EN 14181 (AG3)

Air Guidance Note 4: Air Dispersion Modelling from Industrial Installations - Guidance Note (AG4)

Air Guidance Note 5: Odour Impact Assessment Guidance for EPA Licensed Sites (AG5).

This guidance note is intended for use by holders of EPA licences (licensees) and consultants. The Agency advises licensees to have regard to this guidance when undertaking or outsourcing any work relating to VOC emissions from landfill surfaces.

Throughout the guidance note there are examples given of licence conditions which are typical of those found in Irish Waste licences. In reality, licence conditions may vary somewhat from one licence to the next, due to local circumstances, so reference should be made to the current licence document for the site-specific licence condition.

This guidance note will be the subject of periodic review and amendment. The most recent version of this note is available on the Agency's website: <http://www.epa.ie/> if you have any particular queries regarding this document please contact Mr Kieran Fahey at [k.fahey@epa.ie](mailto:k.fahey@epa.ie).

## Glossary and Interpretation of Terms

Biodegradable Waste	Any waste that is capable of undergoing anaerobic or aerobic decomposition, such as food, garden waste, sewage sludge, paper and paperboard.
Capped Area	For the purposes of <u>this guidance alone</u> this term refers to any area of a landfill that has been finally capped in accordance with the EPA waste licence for that landfill. No other area, such as temporary capped areas etc, are considered capped areas in this guidance note.
Features	This includes both engineered and naturally occurring features. See examples in Section 2.4, page 11.
Landfill Gas	All gases generated from the landfilled waste.
NMVOC	Non-methane volatile organic compounds.
Methane Concentration	The concentration of methane, or total flammable gas as measured by an FID, expressed as ppm v/v or as percent by volume.
Methanogenesis	The stage in the waste degradation process when the bulk landfill gas composition comprises a mixture of carbon dioxide and methane. It typically commences within 3-6 months after emplacement of waste.
Open Surfaces	All landfill surfaces, whether uncapped, or capped with either a daily cover, temporary/intermediate cap, or permanent final cap.
ppmv or ppm v/v	This is part(s) per million by volume. It can also be written as ppm v/v. It is a volumetric measurement of the concentration of a parameter; in this case VOC. 1ppm is 0.0001%, 10,000ppm is 1%.
VOC	Volatile organic compounds. This is total VOC including methane as well as trace compounds.
Working Face	The area of the landfill facility in which waste, other than cover material or material for the purposes of the construction of specified engineering works, is being deposited.
Trigger Level	A parameter value specified in an EPA licence, the achievement or exceedence of which requires certain actions to be taken by the licensee. Appropriate actions are normally specified by the facility's EPA inspector.

## **1. Introduction**

### **1.1 Scope and Purpose of Guidance Note**

The aim of the guidance note is to provide concise ‘best-practice’ guidance for landfill managers, consultants, technicians and any other personnel in charge of monitoring VOC emissions from landfill surfaces and reporting on the findings in compliance with EPA licence conditions. The guidance note clarifies how the EPA expects VOC emission monitoring events to be carried out and reported upon thereby ensuring results of high standards with regard to accuracy and reliability.

This guidance note is divided into seven sections:

1. Introduction – this current section provides relevant background information.
2. Surface emissions of landfill gas - explains landfill gas generation, provides an overview of VOC surface emissions over time.
3. Monitoring equipment – overview of suitable types of analytical equipment and global positioning systems.
4. Planning for the survey – the carrying out of a desk study prior to the survey.
5. Monitoring procedure – monitoring of the various areas and discrete landfill features as per licence conditions. Some health and safety aspects are also covered.
6. Mapping – the requirements and expectations for the graphical presentation of monitoring data.
7. Reporting – the required content for a VOC surface emissions survey report.

### **1.2 Regulatory Background**

Regulation of waste management in Ireland is through the Environmental Protection Agency Acts, 1992-2007, and the Waste Management Acts, 1996-2010. In summary, these legislative documents:

- Allow for the provision of measures to improve national performance in relation to the prevention, reduction and recovery of waste.
- Provide a regulatory framework for the application of higher environmental standards, particularly in relation to waste disposal.
- Designate the Agency as the licensing authority for landfills.

In addition, the European Union’s “Landfill Directive” (Council Directive on the landfill of waste 99/31/EC) sets stringent operational and technical requirements for landfills, and provides for measures, procedures and guidance to prevent or reduce negative impacts on the environment and on human health.

### **1.3 Available Guidance**

The EPA has two guidance note series that are relevant to this document.

The *Landfill Manuals* series

*Landfill Monitoring* (2<sup>nd</sup> Edition, 2003); from the *Landfill Manuals* series provides guidance on the design and implementation of a monitoring programme in order to accurately assess the impact of a landfill on its surrounding environment.

The *Air Guidance Note* series

The Air Guidance Note series, of which this document is the sixth, is concerned with the general theme of air pollution monitoring. Details of other documents in this series are included on page 4.

In addition, in 2010 the Agency published an *Assessment of Landfill Gas Emissions and Management Systems at 29 EPA licensed landfills*. All EPA publications are available online at [www.epa.ie](http://www.epa.ie).

#### **1.4 Relevant Licence Conditions**

To control odour emissions, typical conditions in EPA landfill licenses include:

*Following completion of waste acceptance in any cell/sub-cell, the licensee shall, on a bi-annual basis, arrange for the carrying out of an independent assessment and report on surface VOC emissions at the facility;*

and

*In relation to surface emissions from the waste body and identified features, the following shall constitute a trigger level:*

- *VOC greater than or equal to 50ppmv average over capped area; or*
- *VOC greater than or equal to 100ppmv instantaneous reading on open surfaces within the landfill footprint; or*
- *VOC greater than or equal to 500ppmv around all identified features.*

#### **1.5 Condition Interpretation**

Taking into account the specific definitions available on page 5 of this document the licence conditions outlined in Section 1.4 shall be interpreted in the following way.

The first condition (bi-annual assessment):

The Agency expects that any cell containing waste, including the active cell, but excluding the working face, be assessed for surface VOC emissions every six months. Guidance on a suitable reporting format is available in Section 7.

The second condition (trigger levels):

*VOC greater than or equal to 50ppmv average over capped area*

This relates to final capped areas, that is, any area under a permanent cap only. It is the average of the individual readings (excluding those readings relating to features) taken in the final capped area.

*VOC greater than or equal to 100ppmv instantaneous reading on open surfaces within the landfill footprint*

The 100ppm instantaneous value specified for open surfaces should be interpreted to relate to any one monitoring location in any area of the landfill. The working face is not monitored. Instantaneous emissions results from individual monitoring locations that are in areas which are under daily cover, intermediate cover, temporary cap or final cap should read no more than 100ppm.

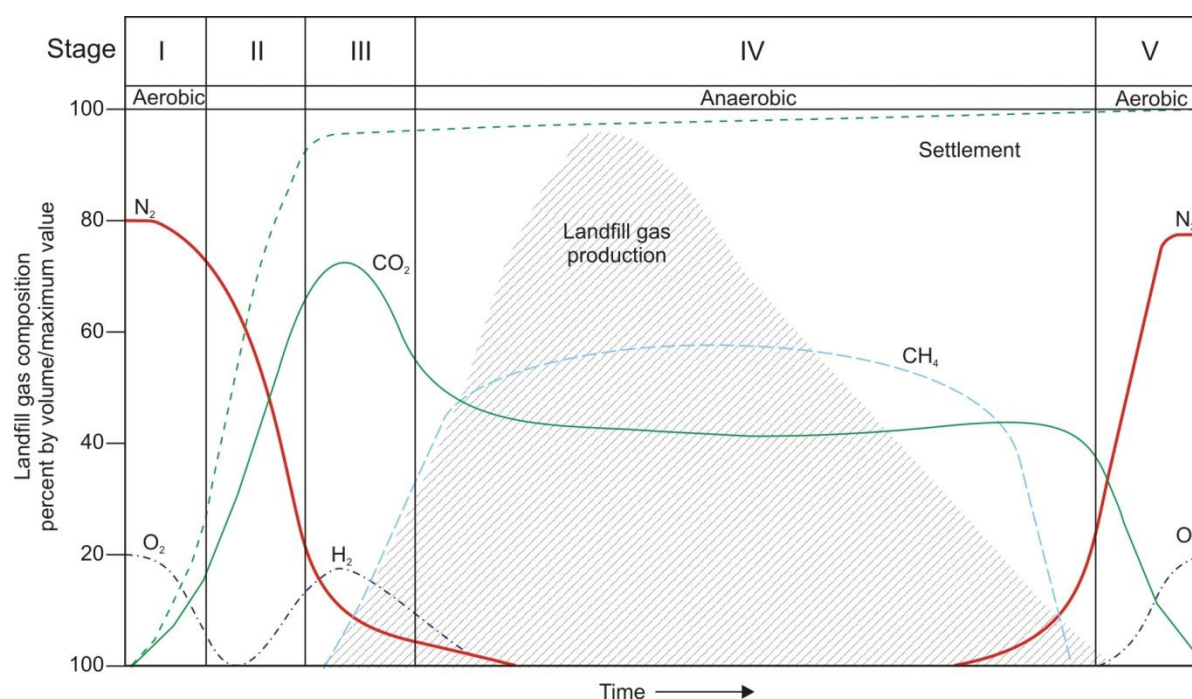
*VOC greater than or equal to 500ppmv around all identified features*

The 500ppm value applies to features irrespective of where they are. This is an instantaneous measurement for each feature and is not averaged. A comprehensive listing of features surveyed should be provided in the monitoring report.

## 2. Surface Emissions of Landfill Gas

### 2.1 Landfill Gas Generation and Composition over Time

The waste decomposition process involves several stages during which different groups of bacteria break down complex organic substances such as carbohydrates, proteins and lipids into successively simpler compounds. Figure 1 illustrates the production of gas from a body of waste over time in an idealised manner.



*Figure 1: Changes in the Composition of Landfill Gas over Time (based on Farquhar and Rovers, 1973 with additions of the post closure stage (Stage V), and also includes the gas production rate during the life of the landfill, and settlement rates).*

Upon commencement of the degradation process, bacteria consume any oxygen contained within the waste and release mainly carbon dioxide, water and heat. Methane production (methanogenesis) only starts after anaerobic conditions have been established in the waste, typically 3-6 months after waste placement. During peak gas production the bulk gas consists typically of 50 to 60% methane and 40 to 50% carbon dioxide. Once all biodegradable substrate in the waste has been consumed, gas production slows and the gas composition in the waste returns to atmospheric conditions.

Apart from methane and carbon dioxide there are more than 500 substances contained in landfill gas. Many of these trace gases are toxic, odorous, or both. Their combined total concentration is typically in the order of a few percent. Hydrogen sulphide, a toxic and highly odorous trace gas, may occur at up to 5%.



Trace gases only occur in small quantities compared to the bulk gases methane and carbon dioxide. Their release to atmosphere occurs mainly because bulk landfill gas, which by definition is produced in much larger volumes, acts as a carrier gas and flushes the trace gases out of the body of waste and into the surrounding environment.

Even though methane itself is odourless it acts as a marker for the presence of landfill gas including odorous trace components. Surface emissions monitoring for methane is therefore a reliable method for indicating the presence, or otherwise, of potentially odorous gas.

#### *Volatile Organic Compounds*

Certain compounds of both bulk and trace landfill gas can be defined as VOCs. These include the chemical groups known as alcohols, aldehydes, alkanes, aromatics, halocarbons, ketones and halogenated derivatives of these substances. VOCs are often grouped into methane and other non-methane VOCs (NMVOCs). While many VOCs have no odour (such as methane), a number of VOCs are highly odorous, for example the sulphur containing mercaptans and dimethyl sulphides. Hydrogen sulphide, also generated within the waste, and also highly odorous, is not classified as a VOC.

#### *Sources of VOCs in Waste*

VOC's are produced during anaerobic waste degradation within the landfill's body of waste. A smaller amount may arrive into landfills from waste materials such as paints, glues, adhesives or solvents that are consigned to landfill.

#### *Landfill gas composition*

Within a landfill site boundary, the gas composition encountered is usually a mixture from two sources: landfill gas and atmospheric air. Typical compositions of both are detailed in Table 1. As the amount of atmospheric air in landfill gas increases, monitoring equipment needs to be increasingly sensitive to detect a landfill gas component.

*Table 1: Typical Gas Compositions on Landfill Sites*

<b>Gas Component</b>	<b>Air (%)</b>	<b>In-Waste Landfill Gas Composition (%)</b>	<b>Landfill Gas in the Gas Collection System (%)</b>	<b>Landfill Gas in Perimeter Borehole (%)</b>	<b>Landfill Gas Surface Emissions (%)</b>
Nitrogen	78	0	<20 N <sub>2</sub> +O <sub>2</sub>	78	78
Oxygen	21	0	<7	21	21
Methane	0.0002 (2 ppm)	50 - 60	40 - 60	<1	0.0002 - >1 (2 ppm - > 10000 ppm)
Carbon Dioxide	0.03	40 - 50	30 - 50	<1.5	0.03 - >1
Hydrogen Sulphide	0	0.0001 - 5 (1 – 50,000 ppm)	0.0001 - 5 (1 – 50,000 ppm)	<.05 (0.001 – 500 ppm)	<0.00001 (1 – 500 ppb)
Total NMVOCs	<0.0001 (<1 ppm)	<1	<1	0- >0.01 (0 - >100 ppm)	0 - >0.1 (0 - >1000 ppm)

## 2.2 Benefits of Measuring Surface Emissions

VOC surface emissions surveys can be a fast, reliable and cost effective method for identifying significant emission sources of landfill gas from a landfill surface, and for demonstrating compliance after remediation of such emission sources.

VOC surface emission measurements can provide the following information:

- The location of the main sources of surface emissions on the site,
- Where to focus remediation efforts,
- Whether previous remediation effort has been successful,
- Where significant amounts of landfill gas that could otherwise have been flared or beneficially used for power generation are being lost,
- Where the licensee may need to focus remediation efforts to improve the gas collection efficiency.

Surface emission measurement cannot:

- Assess flare efficiency,
- Tell a licensee how to undertake remediation,
- Identify other non landfill gas odour sources,
- Indicate how long a landfill may remain below trigger level emissions after a VOC surface emissions survey.

## 2.3 Landfill Gas Balance

Landfill facilities accepting biodegradable waste generate landfill gas. Generation rates vary throughout the landfill's life and between individual landfills. Initially, a small proportion of gas may temporarily be stored within the body of the landfill. However as gas generation rates increase, it will inevitably leave the waste body by various pathways. Active gas management may be by flaring of the gas, or by direct or indirect utilisation of the gas as a renewable resource. Landfill gas which is not collected may be emitted laterally and/or vertically through the surface of the landfill, leading to potential odour and greenhouse gas impacts. If the landfill is capped, microorganisms present in the aerobic regions of the soil will oxidise a proportion of the methane to carbon dioxide, a process called biological methane oxidation.

The mass balance of gas in a landfill can be summarised by the following equation:

$\text{Total Gas Generated} = \text{Gas Utilised} + \text{Gas Flared} + \text{Lateral Emissions} + \text{Surface Emissions} \\ \text{(including methane oxidation in the cap)} \pm \text{Short Term Storage}$
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## **2.4 Landfill Features and Points of Surface Emission**

Uncontrolled surface emissions can be a major source of odours emitted from landfill sites. Such sources may be either area or point in nature.

Examples of area sources include:

- Open, un-capped areas, e.g. operational cells and working faces,
- Areas under daily cover,
- Areas under intermediate cover or temporary cap, e.g. surfaces not yet at final levels but not currently being filled,
- Flanks, either un-capped or under various types of cover,
- Areas under final capping.

Examples of point sources include engineered features, such as:

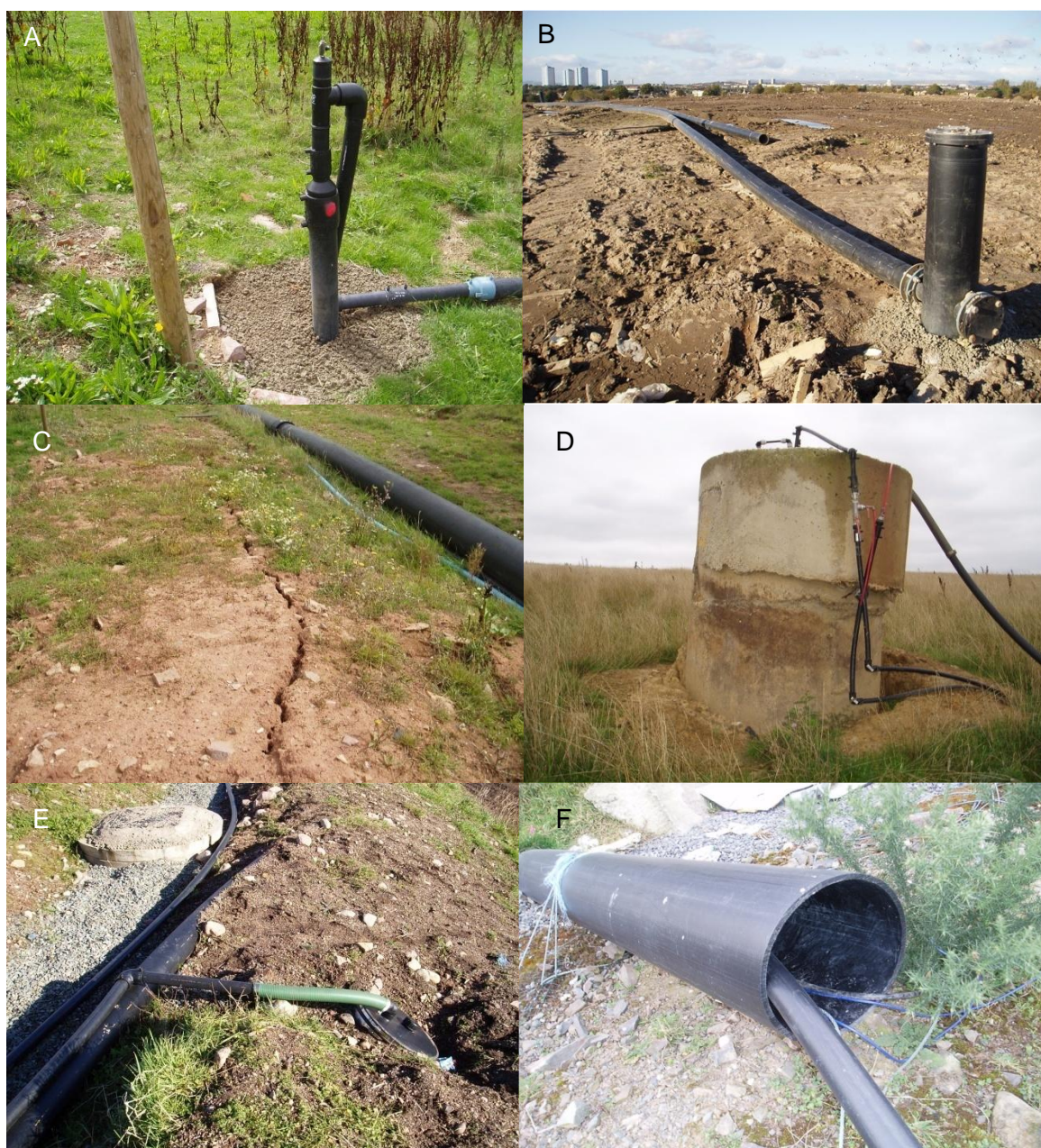
- Leachate chambers,
- Leachate side-slope risers,
- Gas wells,
- Service chambers,
- Monitoring points,
- Pipework below ground.

Other point sources may not specifically be engineered features, these include:

- Surface fissures and settlement cracks in the cap,
- Landfill edge features where lining and capping systems join, these may be particularly noticeable in steep wall lining systems,
- Uncapped flanks (also an area source),
- Points/areas of vegetation stress.

Some of the above listed sources may be either point or area in nature.

Some examples of likely sources are shown in Figure 2 below. Emissions from such features may arise either through leakages of the feature itself or through deficient sealing where the features penetrates the cap.



**Figure 2: Examples of Engineered Features and Surface Defects.** A: Gas well in final cap. B: Gas well in temporary cap. C: Settlement crack and vegetation stress at edge of landfill. D: Leachate tower. E: Sealed side-slope riser. F: Open side-slope riser venting to air.

In 2010, the Agency published an *Assessment of Landfill Gas Emissions and Management Systems at 29 EPA licensed landfills*. The study concluded that surface emissions monitoring in conjunction with gas collection infrastructure assessments, is an effective tool for assessing landfill gas and thus odour emissions. The study identified some of the main causes of surface emissions, including:

- Inefficient gas collection; identified underlying factors included perched leachate wells, inadequate condensate removal, lack of or inadequate absorptive capacity, inadequate flow control and inadequate balancing of the gas feed from wells to flares,

- Emissions from leachate side-slope risers and leachate chambers due to inadequate sealing of the features and the absence of landfill gas abstraction,
- Flanks and sloped areas were found to have the highest surface emissions potential among all area sources.

Over the past decade there have also been several UK based research projects regarding surface emissions from landfills (Barry et al (2004a-c) and Environment Agency (1999)). These findings agree and support those found by the Agency. In summary, these methane focused projects found:

- Emissions from the surfaces of landfills vary according to age, depth, filling regime, waste quantity, seasonality, cap type and efficiency of the landfill gas collection system,
- An engineered cap combined with effective gas management can reduce the methane emissions from landfills by at least three orders of magnitude,
- Methane emissions on operational surfaces can be much higher than from completed caps,
- Significant methane emissions arise from passive venting systems such as open gas vents,
- Gas generation and surface emissions rates can be affected by a wide range of variables including physical and meteorological conditions,
- Over time, methane flux rates increase with a maximum flux occurring at approximately 20 - 24 months from waste placement. Methane can become present in the gas within 1 - 2 months of waste placement. Full methanogenic gas production rates occur from approximately 3 to 6 months after emplacement,
- Vertical gas permeability of the waste is three to five times lower than the horizontal permeability, with higher fluxes emitted from waste side slopes and near landfill edges,
- Temporary capping reduces surface emissions but not to the same extent as permanent capping.

Table 2 shows typical lower and upper limits of ranges for methane surface concentrations observed at different landfill surface types and at different identified landfill features. Identified features with the highest potential for emission release are open gas wells, leachate chambers and side-slope risers. The largest potential for landfill surface emissions are in the operational area, but areas of daily, temporary or intermediate cover, and landfill flanks, and areas of vegetation stress are also surfaces which may yield potentially high methane concentrations.



*Table 2: Typical Range of Methane Surface Emission Concentrations from Different Landfill Areas and Discrete Features (EPA, 2010)*

<b>Landfill surface type or feature</b>	<b>Typical lower value observed (ppm v/v)</b>	<b>Typical upper value observed (ppm v/v)</b>
Operational Cell	10	>10,000
Daily Cover	1	>10,000
Temporary/Intermediate Cap	1	>10,000
Landfill Flanks	1	>10,000
Permanent Cap with Gas Collection	1	50
Seal around Gas Well, Leachate Chamber or Side Slope Riser	10	>10,000
Inside open Gas Well, Leachate Chamber or Side Slope Riser	100	>10,000
Re-laid Cap over Buried Transmission Pipework	1	1,000
Settlement Cracks, Edge of Site Effects	10	>10,000
Areas of Vegetation Stress	10	>10,000

*Note: 10,000 ppm v/v equals 1 %v/v;*

### **3. Monitoring Equipment**

Two main pieces of equipment are required for VOC surface emissions surveys; a landfill gas analytical instrument and a global positioning system (GPS) device.

#### **3.1 Landfill gas analytical instruments**

A range of analytical equipment is available for landfill gas monitoring, including:

- Multi Gas Analysers,
- Photo Ionisation Detectors (PID),
- Flame Ionisation Detectors (FID).

##### *Multi-Gas Analysers*

Such analysers typically use infra-red technology for the bulk landfill gases (carbon dioxide and methane), and electrochemical cells for other parameters that are present in smaller quantities, e.g. oxygen, hydrogen sulphide and carbon monoxide. Generally, multi-gas analysers are not sensitive enough for surface emissions monitoring as they lack the required resolution to accurately detect trace gases. However, they may be useful to verify very high emission concentrations which exceed the safe operating range of other monitoring technologies.

##### *PID technology*

A Photo Ionisation Detector (PID) contains an ultraviolet light source. Photo ionisation occurs when a sampled atom or molecule absorbs sufficient light energy from the light source to become ionised. The ions produced are then measured at sensor electrodes. The current generated in this manner provides a measure of the sample concentration.

PID technology is only suitable for Non-Methane VOCs (NMVOCs); a PID will not detect methane. As a result a PID is not considered suitable for most VOC surface emissions surveys, but might be suitable as an adjunct for detecting NMVOCs from recently emplaced waste that is not yet generating methane.

#### *FID technology*

Similar to PID but with a hydrogen fuelled flame instead of a UV light source. A sample of gas passes through the flame producing electrically charged ions. These are then measured at sensor electrodes. FIDs are only suitable for flammable gases, which in this application includes both methane and flammable NMVOCs (i.e. most VOCs). Methane can be measured by FID because of the high temperatures achieved by the hydrogen fuelled flame. As outlined in Section 2.1 the presence of methane is a reliable indicator of the presence of other, odorous, landfill gases.

FIDs operate in the required concentration range for assessment against licence trigger levels. FIDs are less sensitive than PIDs to very low VOC concentrations. The FID is the most practicable analyser for the ranges of VOC identified in Table 1.

#### *Required Minimum FID Specification*

Typically an FID analyser needs to have the following properties when used for surface emissions monitoring:

- Resolution: 1 – 10,000 ppm
- Precision: (Repeatability) 3 ppm
- Accuracy: 3 ppm
- Analytical Response Time: 3 - 5 sec
- Pump Rate: Minimum 600 ml/minute
- It is strongly recommended that the equipment be ATEX-certified intrinsically safe.

#### *Specification of Sampling Probe*

An FID is normally supplied with one or more sampling probes. These however tend not to be designed for landfill surface emission monitoring. In order to achieve a more robust and repeatable sampling methodology it may be necessary to place a funnel to the end of the sampling probe. This sampling funnel catches the surface emission under the funnel footprint. A wind deflector, which can be a larger funnel placed over the sampling funnel, can help minimise air turbulence and thus improve data quality. One possible probe design is shown in Figure 3.

The sample volume of the particular FID used will dictate the probe size needed to keep the sample acquisition rate constant based on the face velocity at the probe face. By keeping the sample train as short as practically possible the sample time is optimised.

#### *Sample Response Time*

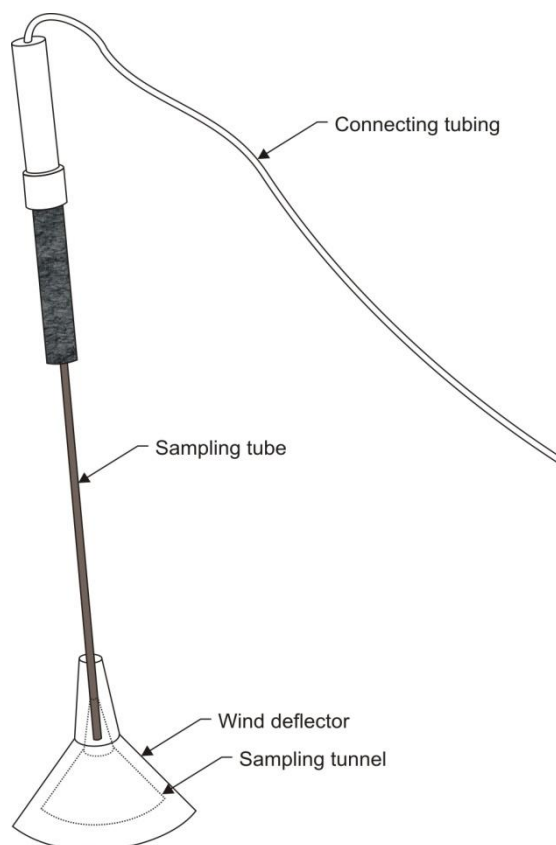
The analytical response time of the instrument is usually 5 seconds or less. It is mainly governed by the time it takes to exchange the gas in the probe while the instrument is sampling from a new location. The length and diameter of the sample tube, the FID pump rate and the sample funnel size all influence the total response time of the FID. In order to work out the sample response time for any one particular FID the following calculation may be used:

Sample response time =  $A/B + C$

A = volume of sampling tube + volume of connection tube + volume of funnel (if used)

B = sample rate / 60 sec

C = Analytical response time (sec)



*Figure 3: An Example of an FID Probe Design*

#### *Methane Flux boxes*

An alternative approach to carrying out a “walk over” style survey (Section 5) is to use methane flux boxes. This involves the placing of a number of boxes on the landfill surface that trap methane. The advantage with this approach is that it is possible to get a rate of methane emissions over time. However the major disadvantage is the lack of spatial coverage possible. While methane flux box assessment is a robust technique, it is not considered useful for satisfying the particular requirements for this guidance document.



### **3.2 Calibration and Maintenance**

The FID needs to be fully calibrated by the manufacturer or supplier of the equipment at intervals of every 6 months, or as otherwise specified by the manufacturers' instructions. Calibration certification shall be included as an appendix of the survey report.

In addition to the full manufacturers calibration the following zero and span routine shall be undertaken on each day of monitoring.

Necessary Calibration gases: Zero gas (0ppm) and 100ppm methane. The survey report should contain cylinder details such as the 'use before' date and any cylinder reference number.

Location: Carry-out the zero-span routine on site.

Frequency: Before, midway through, and after the surface emissions survey, typically therefore at 3-4 hour intervals. Any drift occurring over the day is noted in the site report but not automatically corrected for.

Instrument settling: The FID should be turned on and allowed to settle before being used in any way, including being zero and span checked. The time taken for settlement will depend on individual instruments.

Procedure: The zero and span gases shall be introduced under the same flow and pressure conditions using the sample probe at the end of the sample line. The adjustment procedure shall be as follows:

- a) Feed the zero gas (0ppm) into the FID and set the zero;
- b) Feed the span gas (100ppm) and adjust the instrument accordingly;
- c) Feed the zero gas into the FID once more and check that the reading returns to zero; if not repeat steps a) to c).

Equipment should be maintained and operated as specified by the manufacturer.

The calibration routine outlined above is the minimum acceptable calibration practice. On-site calibration routines which go beyond the above requirements are therefore encouraged. However, deviations from the above should be documented and justified in the survey report.

One deviation to which the Agency is agreeable is the use of additional calibration span gases at concentrations of, for example, 500ppm and 5000ppm (or other as needed).

### **3.3 GPS**

The objective of the monitoring exercise is to locate areas of significant (with regard to licence trigger levels) landfill gas leakage from landfill surfaces. Therefore, it is essential that highly accurate information regarding the positions of monitoring locations be recorded.

A high resolution portable GPS receiver may be adequate; however considering the monitoring grid spacing required, preference is for a base station GPS system, similar to those used for topographical surveys. A base station GPS system will provide the accuracy needed to ensure that remediation exercises, post survey, are optimised.

Typically a GPS receiver needs to have the following properties when used for surface emissions monitoring:

- Resolution/Accuracy of 2 metres minimum- the preferable base station approach should be capable of providing accuracy to <1 metre.

- Capability to store multiple waypoints.

## 4. Planning for the Survey

The survey is undertaken in two stages. The first stage comprises a desk study in preparation for the FID walkover survey. This exercise will assist in planning and carrying out the survey in as time-efficient and thorough a manner as possible. It helps the surveyor to plan ahead for the site visit and to develop an understanding of the current situation at the landfill. It is not envisaged as a time intensive exercise. The second stage, monitoring, is covered in Section 5.

### 4.1 Desk Study

The surveyor should obtain a site base map/drawing from the landfill operator, or other, as appropriate and update it in accordance with the criteria from the relevant licence conditions, that is:

- Indicate all permanently capped areas. The trigger levels of 50ppm average and 100ppm instantaneous will apply here. Identify monitoring locations for this capped area according to the sample grid contained in Table 3. Remember the definition of “Capped area”, for the purposes of this guidance is limited to final caps only.
- Identify and locate all features, engineered and otherwise. The trigger level of 500ppm will apply at these individual locations. Such features will include but are not limited to: gas and leachate infrastructure including gas wells, gas monitoring points, leachate wells, side-slope risers, gas and leachate collection pipework and any projections off/from the waste body. This applies to all features including those occurring on any final cap area.
- Identify the current location of the working face and operational cell. No surveying will be undertaken at the working face. The trigger level of 100ppm will apply for the instantaneous monitoring locations in the operational cell. Any area not under final cap, which is also not a feature and is not the working face shall be monitored against the trigger level of 100ppm for instantaneous readings, no averaging against the 50ppm value need be done here. Note that although the working face is not itself monitored the surveyor is expected to monitor all other areas of the active cell.

The surveyor should review previous survey reports and ensure monitoring is carried out at locations that were previously above trigger levels. Previous survey reports are available from the licensee and the Agency public file.

The surveyor should be aware that areas of anticipated high and medium rate emissions will include:

- The operational cell,
- Uncapped surfaces and flanks,
- Surfaces and flanks with daily cover,
- Temporary capped surfaces,
- Temporary capped flanks and slopes.

Areas of anticipated low rate emissions include:

- Permanently capped and restored areas.

During this planning stage the surveyor should also gather information regarding the gas collection infrastructure at the facility. This information will be needed for the survey report, as per Section 7.

#### **4.2 Weather Conditions**

Surface emission rates and therefore measurement results may be affected by the meteorological conditions prevailing during the survey:

- Reduced surface emission rates may occur during periods of high barometric pressure,
- Water logged soils are less permeable to gas thereby reducing gas emission rates,
- High wind speeds may affect the accuracy of the FID measurements by diluting the sampled surface emissions (however at <75mm above ground these affects may be negligible).

The following meteorological conditions are preferable:

- Low wind speeds, ideally <5 m/s (however if the site is normally windy measurements may have to be undertaken when wind speeds are higher than this),
- Air temperature between 5°C and 20°C,
- Avoid periods after or during particularly heavy rainfall. Do not survey locations where standing water is present,
- No saturated or frozen ground during the survey or within two days before the survey,
- Periods of extremely high or low barometric pressure should ideally be avoided, as should times when it is rising or falling rapidly.

Considering the prevailing weather conditions experienced in this country it may not always be possible to enjoy ideal monitoring conditions. Therefore, if necessary, surveys may be undertaken outside of ideal conditions once it is noted and recorded in the report.

The inclusion of meteorological data for the time period in which the survey was undertaken is a mandatory component of the survey report. As a minimum the following meteorological data should be recorded:

- Average wind speed (m/s),
- Wind direction (direction from where the wind was coming, e.g. SSW), also note deviations,
- Atmospheric pressure (mbar),
- Cloud cover (Okta),
- Temperature (°C),
- Description of wetness or dryness of day,
- Relative humidity (%).

## 5. Monitoring Procedure

With the desk study complete and suitable weather conditions prevailing, the surveyor arrives at the landfill facility.

The FID is switched on, allowed to settle, and the calibration procedure outlined in Section 3.2 is undertaken.

During the time that the instrument is settling, pre-calibration, the surveyor should meet with the landfill manager (or delegate). The landfill manager should check the base map prepared during the desk study and verify its accuracy. Any changes may be completed by hand at this stage. Details regarding the gas collection infrastructure at the facility should also be reviewed by the landfill manager at this stage.

The surveyor should now (if he has not already) prepare the GPS base station or portable GPS device as per the instruments operating instructions. Be aware that a GPS base station may take time to settle. This will vary depending on the instrument used but may be between 10 and 20 minutes on average (See instrument operating instructions).

With the desk study base map now verified, the FID calibrated and the GPS system set up, the surveyor is ready to commence the monitoring exercise.

### 5.1 Where to monitor

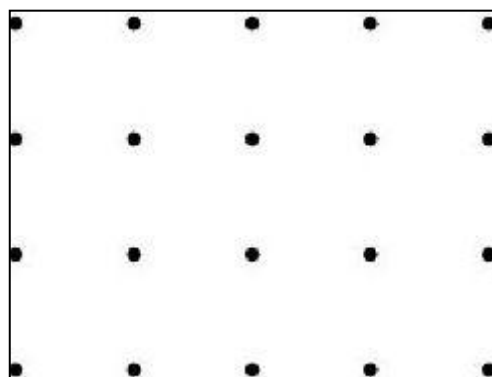
*Table 3: Sample Grid Spacing for VOC Surface Emissions Monitoring.*

Location	Sample Grid Spacing (m)	Trigger Level (ppm)
Working Face	Not sampled	Not applicable
Operational cell	2-5*	100
Any cell or flank of cell not under permanent final cap	2-5*	100
Permanently capped cell (Including restored areas)	30	50 average
		100 instantaneous
All features	Not applicable	500

\* The smaller the grid spacing the more beneficial the exercise will be to the landfill management's remediation efforts. Deciding on a value between 2-5 metres is a compromise between thoroughness of coverage and pragmatism; however, preference is for short (dense) grid spacing. Monitoring to a dense sampling grid will initially incur extra time on site but it will ultimately assist in reducing both remediation costs and odour occurrence. The results of previous survey results will also influence the sample density choice from within the 2-5m range.

The sample grid spacing as outlined in Table 3 is implemented as follows:

The surveyor enters the area of the designated cell or group of similar cells (e.g. the area of the non-permanently capped cells). Any available corner can be considered as the starting point. This point represents (0,0) on the X and Y axis of the area. This will be the first monitoring location. The second monitoring location will be the distance indicated in Table 3 away from the first point in an approximately straight line on either the X or Y axis. The third follows the same routine, and so on. The process is repeated until there is a monitoring result for every location based on 2-5 or 30m resolution, as per Figure 4.



*Figure 4: Layout of predefined sample locations in an idealised landfill cell. Distance between locations varies depending on Table 3.*

## **5.2 How to monitor**

Using the calculation in Section 3.1 the surveyor should be aware of the instruments response time.

At each sample location the probe is placed less than approximately 75mm above the landfill surface. This allows it to clear any surface roughness and minimises significant wind disturbance, while at the same time reducing the likelihood of drawing in particulate matter. The GPS position of the monitoring location is logged and, once the sampling time has elapsed, the monitoring result is recorded.

Using the GPS as a guide the surveyor begins the walk to the next monitoring point in the sample grid. The surveyor shall walk slowly to the next point at a speed of <0.5 metres per second. While doing so, the FID sampling probe is kept at the same height above ground and the FID results are continuously monitored by the surveyor. Any FID reading from any area between the two monitoring points that is approaching or exceeds the 100ppm value shall be further investigated in detail. That is, the surveyor shall undertake a full response time monitoring exercise at the location. The spatial extent of the surface emission is monitored and mapped. Following this extra monitoring point, which shall be deemed “discrete” (as opposed to the predefined locations on the grid outlined in Table 3), the surveyor shall return to the next location according to the predefined sample grid, always walking slowly and continuously monitoring between sample locations.

The purpose of this technique is to allow flexibility in the sampling locations and not to just stick rigidly to the fixed grid of predefined locations.

The VOC surface emissions monitoring result and the GPS location (National Grid coordinates) of all sample points, both predefined and discrete, shall be recorded by the surveyor. The monitoring result for any location shall be a single value representing the peak instantaneous reading observed at that monitoring point.

Advanced FID instruments with proven rapid response times may allow the surveyor to continuously monitor in a roving ‘kinematic’ manner that does not require the surveyor to stop at each predefined monitoring location. In such circumstances the monitoring exercise will be achievable in an efficient manner. For other, less advanced, FIDs the response time will be such that it is necessary to stop when monitoring at the predefined monitoring locations.

The overall objective of this monitoring technique is:

- to obtain a monitoring result for each predefined monitoring location in a resolution according to Table 3, and,

- to map the spatial extent and peak VOC reading of any surface emission encountered between the predefined monitoring locations.

#### *Monitoring at features*

At this stage of the monitoring survey all features shall have been identified from both the desk study exercise and the meeting with the landfill manager on the day of the survey.

The exact point at which to monitor VOC emissions at a feature will depend on the characteristics of individual features. Table 4 specifies some examples.

*Table 4 FID Measurement Location at Different Features*

<b>Feature</b>	<b>Cap Penetration</b>	<b>Open Vent</b>
Side Slope Riser	√	√
Leachate Chamber	√	√
Gas Well	√	X
Monitoring Point	√	X

For each discrete feature one single value representing the maximum reading observed is recorded. The surveyor should state in the report whether this emission (VOC leakage) was associated with a vent or with cap penetration (or other as appropriate), i.e. provide a useful description of how/from where the feature leaked.

If a feature requires measurements both at the cap penetration and inside the feature's opening, two values are reported.

Again, the necessary monitoring time needed for each individual location will depend on the calculation in Section 3.1.

#### *Close Out meeting*

Once the monitoring exercise is complete the surveyor should again meet with the landfill manager/delegate to provide information regarding significant emissions. The landfill manager should be made aware of the summary findings, and be provided with details regarding the locations of any trigger level exceedences.

### **5.3 Health and Safety**

Methane is highly flammable and in certain concentrations with atmospheric air can be explosive. FID technology is based on the principle of 'flame ionisation'; it uses hydrogen to fuel a flame. This constitutes a potential ignition source and can thus trigger an explosion. It is therefore strongly recommended that the equipment used be ATEX-certified intrinsically safe.

The Agency does not regulate health and safety in the workplace. The Health and Safety Authority (HSA) is the competent body that deals with such issues. This guidance is issued as advice to those who are required by the Agency to carry out work as part of a site's monitoring activities. All health and safety aspects of landfill monitoring work are the responsibility of the personnel carrying out the work and the following should be considered as general guidance only:

- Measurement locations should always be approached with the probe leading,
- The instrument (as opposed to the probe) should not be placed on an uncapped landfill surface or near any point or area source of emission. Rather it should be kept at least 10cm above the ground and therefore outside the zone in which high methane concentrations may occur due to surface emissions,

- The FID instrument should be handled with care as many designs use hydrogen fuel stored under high pressure. The handling of the hydrogen cylinder should only be undertaken in accordance with the manufacturer's instructions.

## 6. Mapping

A high quality pictorial representation of the monitoring results is an essential component of the survey report.

The map should satisfy the following criteria:

- A facility base map that is a computerised engineering drawing should be used.
- Be scaled to fit on a standard A4 size page (or different areas of the landfill can be presented on individual pages, as necessary for clarity)
- Be up-to-date with the filling status of the landfill at the time of the survey.
- Include the outline of, and identify, all cells.
- Graphically represent areas of VOC emission through the use of contours as per Table 5, using appropriate contouring software.
- Identify features with a number on the map. These numbers shall relate to a key which contains the emission values associated with the individual features.

*Table 5: Contour colour scheme for VOC surface emissions.*

VOC Emission (ppm)	Contour colour
31- 49	Grey
50 - 99	Green
100 - 499	Orange
≥ 500	Red

## 7. Reporting

The report should follow the structure as outlined in this section.

### *Cover page*

Site name, address, EPA licence number, report title\*, report date and name of consultancy that undertook the survey where relevant.

\*the report title should be in the following format: Licence number followed by -VOC/Surface Emissions/Year/number(1 or 2, depending on whether it is the facility's first or second of their bi-annual surveys)

Example title: W0000-03-VOC/SurfaceEmissions/2011/1

### *Executive Summary*

Containing name and site number of the facility, the date of the survey, the number and general location of exceedences of the trigger levels and a comparison to previous survey results.

### *Section 1: Survey Details*

Any information relevant to the survey, excluding survey results, should be included here. As a minimum it should contain:

- Date of the survey,
- Reason for carrying out the survey,
- Details of weather conditions that prevailed during the survey with regard to section 4.2,
- Details of the relevant personal competencies of the surveyor. Details of previous experience with similar work should be stated,
- Equipment details: State the brand, model and age for the FID and GPS used. Briefly outline their technical capabilities. In particular state the calculated sample response time of the FID and the accuracy of the GPS. Calibration details, as per Section 3.2, should be included in an appendix,
- Details regarding the current gas collection infrastructure at the facility.

### *Section 2: Survey Results*

Results should be presented in two formats: Tables and contour maps.

#### **Tables:**

For all trigger level exceedences provide the following details:

Location: Cell number or feature name where relevant. Always use the official name for identified features (all landfill gas wells for example will be logically numbered),

Monitoring result: Highest recorded instantaneous VOC emission reading for the sample grid location (either predefined or discrete) or feature name. State the average VOC reading, as per Section 1.4, for the final capped area (that is, if there is a final capped area in the landfill).



**Contour Maps:**

A well presented, accurate and clearly labelled contour map will be an essential output from all VOC surface emission surveys. The map shall meet the criteria outlined in Section 6 of this document.

Completed contour maps from the most recent previous survey at the facility as well as the current desk study map should also be included. Maps should always be clearly identified with the date of the survey which they represent. This will allow for clear and unambiguous comparisons of the landfill surface over time and allow landfill operators to see the affects of their remediation efforts.

All data, electronic or otherwise, collected during each survey should be retained on site by the licensee. The data shall be made available to the Agency upon request.

*Appendix*

The Appendix should contain documentation of the calibration process and certification of the equipment as per the requirements of Section 3.2.

## 8. References and Further Reading

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ESA, 2005b: Area classification for landfill gas extraction, utilisation and combustion. Industry Code of Practice. Esa ICoP 2. Edition 1.

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