



Environmental Protection Agency
Office of Environmental Enforcement (OEE)

Guidance Note on Landfill Flare and Engine Management and Monitoring (AG7)

April 2012

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EXECUTIVE SUMMARY

The Environmental Protection Agency has developed this Air Guidance Note (AG7) to assist waste licensed sites in the management and monitoring of landfill gas flares and engines emissions. It is designed to provide the relevant knowledge and guidance to licensees and their emission monitoring contractors.

The document introduces the concept of site specific risk assessments whereby on a case-by-case basis, landfill flare and engine operation, monitoring and maintenance practices outlined in a facilities waste licence may not be suitable for a particular site at a particular stage of its life. Under these circumstances an assessment is required to evaluate potential conflicts between achieving emission limit values and the management of fugitive landfill emissions.

The essential points of this guidance document relate to:

- Descriptions of the salient points of landfill gas production and composition along with the main components of a flare and engine
- Recommendations on parameters, frequency and associated emission limit values for both continuous and non-continuous monitoring programmes
- The difficulties in undertaking monitoring of flares and engines emissions and the specific health and safety considerations which the licensee and monitoring contractors should take cognisance of
- Sampling and monitoring methods to ensure a consistent and transparent procedure for measuring emissions from flares and engines across all sites
- Standardised reporting requirements for emission monitoring data and compliance assessments to the EPA
- Identification of key operational parameters impacting emissions, including extraction flow rate, inlet gas methane concentration, inlet gas oxygen concentration and temperature
- The introduction of an operations and maintenance checklist for monitoring contractors to be submitted as part of an emission monitoring report which will determine:
 - Whether or not the monitoring assessment of respective units is representative of historical day-to-day operations and compliance
 - Whether or not unit operation is being managed to ensure compliance with ELVs or ELVs at the expense of facility fugitive emissions.

PREFACE

Introduction to the Environmental Protection Agency

The Environmental Protection Agency (EPA) administers a wide range of licensing, enforcement, assessment and monitoring activities. The Office of Environmental Enforcement (OEE) operates under the control and direction of the Board of the EPA dedicated to the implementation and enforcement of environmental legislation in Ireland.

The OEE's main functions are to:

- Improve overall compliance with environmental protection legislation
- Raise awareness about the importance of enforcement of environmental protection legislation
- Enforce Integrated Pollution Prevention and Control (IPPC) licences and waste licences
- Audit and report on the performance of local authorities in their environmental protection functions, including:
 - Prosecute, or assist local authorities to prosecute, significant breaches of environmental protection legislation, in a timely manner
 - Assist local authorities to improve their environmental protection performance on a case by case basis, through establishing an enforcement network to promote information exchange and best practice, and by providing guidance

The OEE approach seeks to provide information and advice via guidance to those it regulates to ensure environmental improvements while ensuring value for money.

Existing Air Guidance Notes

The EPA has released six air guidance notes to-date:

- **Guidance Note on Site Safety Requirements for Air Emissions Monitoring (AG1)ⁱ** describes the facilities and work practices that must be in place for safe and effective monitoring of air emissions
- **Air Emissions Monitoring Guidance Note #2 (AG2)ⁱⁱ** is one of a series of guidance notes that the OEE has planned on the general theme of air pollution monitoring
- **Air Guidance Note on the Implementation of I.S. EN 14181 (AG3)ⁱⁱⁱ** focuses on the implementation of I.S. EN 14181 - Quality Assurance of installed Automated Monitoring Systems (AMS)
- **Air Dispersion Modelling from Industrial Installations Guidance Note (AG4)^{iv}** seeks to present general principles and suitable methods that may be used to assess and report on the impact of air emissions from licensed industrial installations
- **Odour Impact Assessment Guidance for EPA Licensed Sites (AG5)^v** describes appropriate methods for conducting field assessments
- **Air Guidance Note - Surface VOC Emissions Monitoring on Landfill Facilities (AG6)^{vi}** sets out appropriate methods and reporting for any work relating to the measuring of volatile organic compounds (VOC) emissions from landfill.

Purpose and Objectives of this Guidance Note (AG7)

This guidance note is specifically focussed on landfill gas flares and engines sources. While the common techniques used to monitor emissions from an industrial source are broadly suitable for use on landfill flares and engines, the monitoring of landfill gas emissions and in particular flare emissions, have a number of practical difficulties and monitoring is frequently problematic.

The objectives of this guidance note are to:

- Specify emissions monitoring requirements for landfill flares and engines (i.e. allowable emissions limits, monitoring frequency, etc.)
- Provide a consistent and transparent procedure for measuring emissions from landfill flares and engines
- Provide clear guidance on sampling and monitoring methods to be used
- Provide clear guidance on the reporting requirements for compliance assessment
- Provide guidance for assessing flare and engine performance and efficiency
- Provide guidance on the operation and maintenance of landfill gas engines and flares.

This air guidance note (AG7) is intended to provide licensees with guidance on the correct management of landfill gas flares and engines in order to minimise emissions. It also provides licensees with details on the required sampling locations, facilities and services required for monitoring as well as criteria to consider when hiring a competent emission monitoring contractor to undertake such testing for a facility.

This guidance note is also intended to outline to monitoring contractors the difficulties in undertaking monitoring of flares and engines, provide details on what should be included in a monitoring plan, standard methods for monitoring, quality control and uncertainty with regards to emission monitoring and the requirement to assess operation and maintenance practices of flares and engines while onsite.

This note should be read in conjunction with the Guidance Note on Site Safety Requirements for Air Emissions Monitoring (AG1) (2010) and Air Emissions Monitoring Guidance Note #2 (AG2) (2007).

Revision of Document

This guidance note may be subject to review or amendment. The EPA website (www.epa.ie) will maintain the most up to date version of this guidance note. Please contact airthematic@epa.ie with any queries.

Disclaimer

This guidance note, and particularly the templates contained in the Appendices, represents the authors' judgement of the best available techniques and practices for landfill gas flare and engine monitoring, operation and maintenance. As such, it may not cover all situations and it may be necessary to employ variations to the methods described in this note by agreement with the EPA.

Description of Guidance Note Sections

Section 1 Introduction describes the various types of landfill gas flares and engines and outlines their basic components. It discusses landfill composition and combustion as well as outlining factors that influence emissions and the associated impacts of these emissions.

Section 2 Recommendations on monitoring parameters, frequency and associated emission limit values provides recommendations on continuous and non-continuous monitoring requirements for landfill gas flares and engines and provides emissions limit values for specific parameters. The concept of design certification and site specific risk assessment is also introduced.

Section 3 Emission monitoring of flares and engines describes how an emission contractor should undertake an emissions assessment. This section discusses the practical difficulties in monitoring landfill flares and engines, outlines health and safety requirements, monitoring protocols, standard methods for emission measurement, quality control, uncertainty and reporting requirements.

Section 4 Recommended Flare and Engine Operation and Maintenance Practices provides guidance on the operation of landfill flares and engines, along with typical routine maintenance practices. The requirement for standby capacity, correct unit sizing, commissioning and decommissioning and the impacts gas collection infrastructure can have on flare and engine operation are also discussed.

Figure 0.1: Quick Reference to Guidance Note

Section	Guidance Note Section	Guidance Note Relevance
1	Introduction	All users
2	Recommendation on monitoring parameters, frequency and associated emission limit values	Licencees & Air Monitoring Contractors
3	Emission monitoring of flares and engines	Licencees & Air Monitoring Contractors
4	Recommended Flare and Engine Operation and Maintenance Practices	Licencees & Air Monitoring Contractors

1. INTRODUCTION

1.1 Landfill gas flaring and utilisation

Section 4 of Annex 1 of the 1999 EU Landfill Directive^{vii} outlines the gas control requirements for all classes of landfills. The specific requirements with regards to treatment and use of landfill gas are:

- 4.2 *Landfill gas shall be collected from all landfills receiving biodegradable waste and the landfill gas must be treated and used. If the gas collected cannot be used to produce energy, it must be flared.*
- 4.3 *The collection, treatment and use of landfill gas under paragraph 4.2 shall be carried on in a manner which minimises damage to or deterioration of the environment and risk to human health.*

This Directive was transposed into Irish law by the Waste Management Licensing Regulations 2000 as amended and the Waste Management Act 1996 – 2011.

1.1.1 Flares

The main types of flares are open flares (elevated stack flare) and enclosed flares (shrouded flare).

Open Flare

Open flares burn landfill gas as open flames, although a windshield is normally fitted. Combustion occurs at the flare tip which is elevated from the ground. Only basic combustion control is available, if any. As combustion is in an open flame and unconfined, luminous flames increase heat losses and high combustion temperatures cannot be achieved. Also landfill gas residence time is very short and cannot be controlled. In addition, emissions from an open flare are not easy to measure and interpret.

Open flares operate at a lower methane (CH₄) content than high calorific enclosed flares, typically at methane concentrations > 20 percent volume per volume (%v/v). However, at these concentrations they may be unable to sustain high enough temperatures to achieve optimum combustion conditions. Open flares are less expensive and have shorter procurement times than enclosed flares.

The use of open flares is generally not allowed on regulated landfill sites due to the requirement in waste licences for high combustion temperatures and specific residence times. Currently, there are 9 open flares installed in landfill sites in Ireland as emergency backup units. Open flares are not discussed further in this guidance document.

Enclosed Flare

Enclosed flares burn landfill gas at ground level in a vertical, cylindrical or rectilinear enclosure (shroud). This enclosure reduces noise, luminosity, heat radiation and provides wind protection. The enclosure is often insulated to reduce heat losses and allow operation at higher temperatures. Combustion control is normally provided and this flare type can retain landfill gas at the design temperature for a specified period of time within a combustion chamber of adequate volume. Therefore, enclosed flares provide for better combustion conditions than those found in open flares.

There are two types of enclosed flares: high calorific and low calorific. The most common enclosed flare used in Ireland is the high calorific flare. These flares typically require CH₄ concentrations > 30 %v/v though it is sometimes possible to sustain combustion with CH₄ concentrations as low as 20 %v/v (with flare modifications) once the flare is running at temperatures >1,000°C. Allowable oxygen (O₂) typically is less than 6% v/v.

While low calorific flares are used across Europe, they are not used in Ireland at present. These flares typically require CH₄ concentrations between 15 and 25 %v/v but once running can sustain combustion with CH₄ concentrations as low as 10 %v/v at temperatures >1000°C^{viii}.

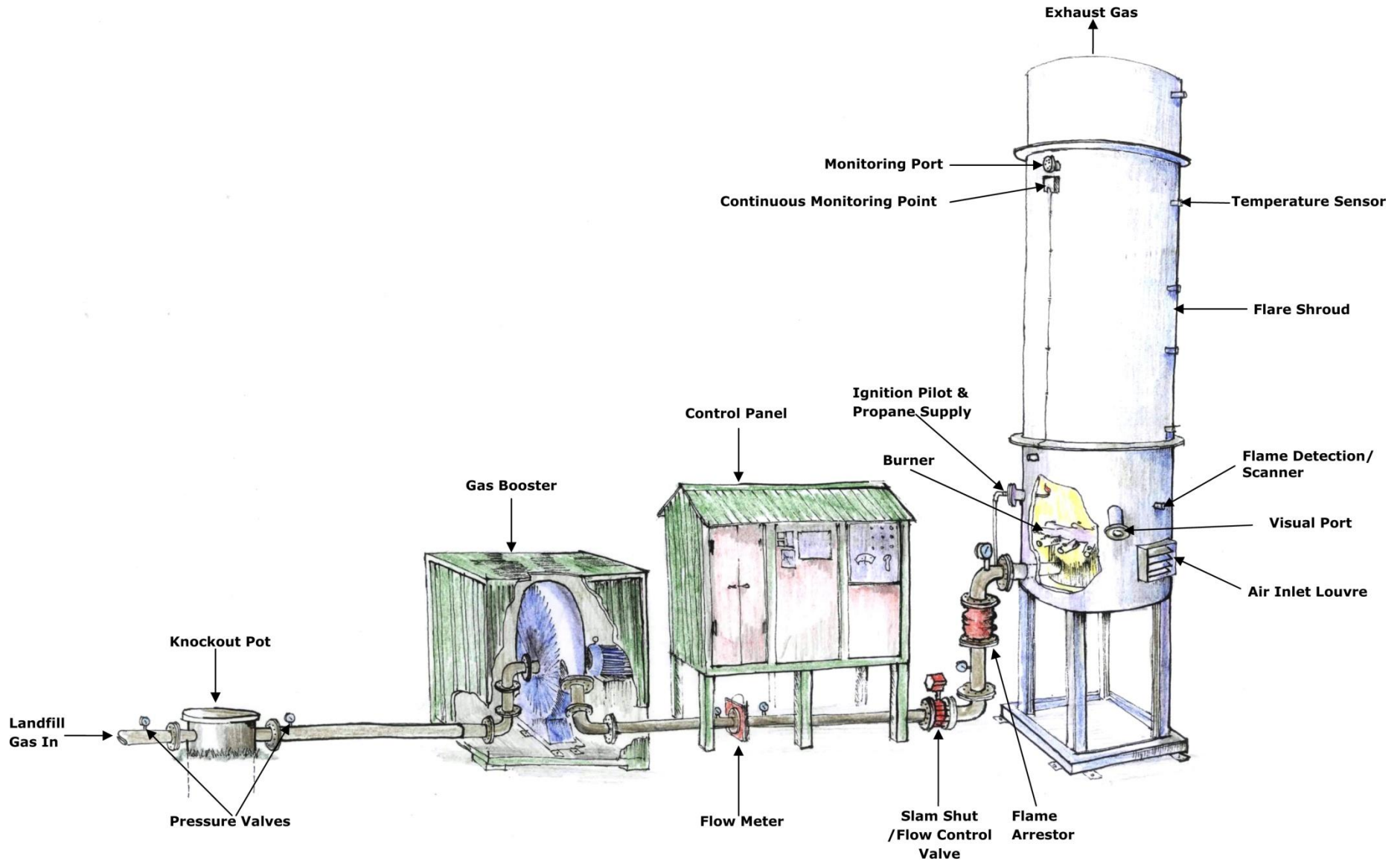
A survey of all landfills in Ireland was conducted in 2011 which advised that there were some 72 flares installed, 9 of which were open with the remaining 63 enclosed flares.

The main components of an enclosed flare as indicated on Figure 1.1 are:

- A **burner** or burners located at the base of a shroud. Burner(s) control mixing of the fuel and air to ensure controlled combustion over a range of landfill gas flow rates
- An **ignition system** (ignition pilot) to provide safe, controlled ignition of the landfill gas
- **Flame detection/scanner** to determine that ignition has occurred and that the burner is operational
- A **flame arrestor and slam shut valve** to avoid flashback of a flame to the fuel feed pipe
- A **flow control valve** to control the landfill gas flow to the flare
- A **combustion air system** to provide air for combustion. There are two methods of providing primary air to support combustion. The first involves mixing of air with the fuel prior to the burner (premix). The second involves the air being drawn into the combustion chamber (diffusion). In both cases, secondary air is drawn into the chamber by natural draught via temperature controlled louvres or open vents. A premixed burner is likely to have higher nitrogen oxides emissions than a diffusion burner
- A **control panel** displaying current flare operational parameters, inlet gas analysis and emission analysis (if available). The flare can be operated from this panel
- A **pressurising system** (gas booster) to ensure that the pressure of the landfill gas is adequate for correct operation of the burner
- A **knock-out pot** to remove moisture and particulate matter from the landfill gas to ensure burners do not become blocked.

The flare height is usually over three times its diameter. The height of the flare has a key effect on the combustion process as it affects the air supply and retention time. Air flow is controlled by louvres or similar and is drawn into the shroud by the natural draught caused by the height of the flare and the buoyancy of the hot combustion gases.

Figure 1.1: Artist impression of a typical flare arrangement



Note: All landfill gas equipment and monitoring equipment should be compliant with ATEX Regulations

1.1.2 Engines

Types of landfill gas engines include reciprocating internal combustion engine (RICE), gas turbine or steam turbine engines. Typical Irish sites use RICE engines with sizes varying between 0.33 kilowatt electrical output (kWe) and 1.4 megawatt electricity (MWe) per unit. Engines have more stringent operating criteria than flares and modern engines typically require $> 45\% \pm 15\% \text{ v/v CH}_4$ and $< 6\% \text{ v/v O}_2$. Most operators will however attempt to control O_2 to $< 4\% \text{ v/v}$.

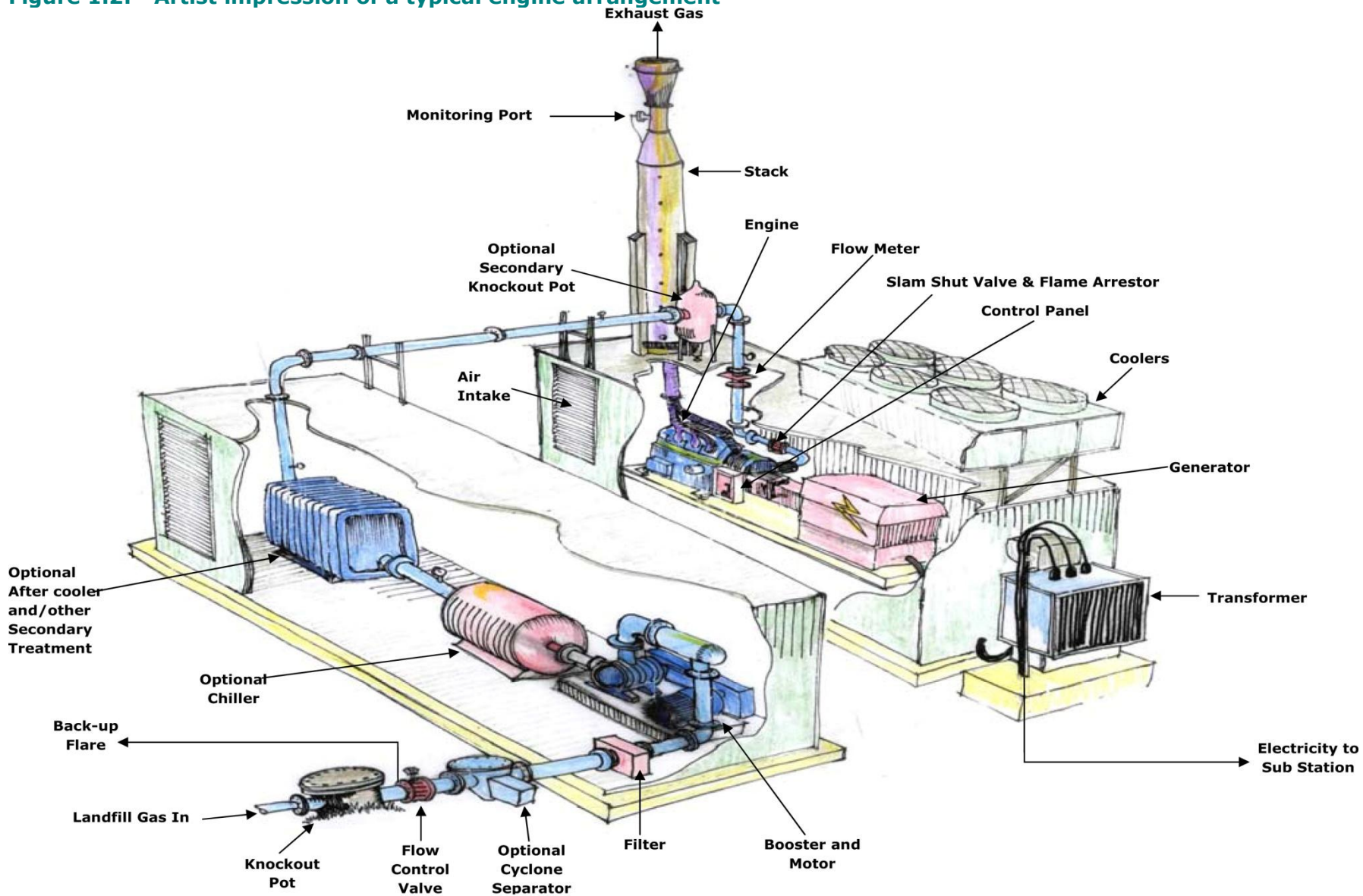
Two principal methods are used to ignite the fuel (gas and air mixture) in the combustion chamber of a reciprocating engine:

- Injection of a small quantity of diesel fuel (dual fuel engines)
- Use of a high voltage spark (spark ignition engines).

Irish landfills typically use spark ignition engines which do not require diesel fuel for start-up. At the time of writing, there were 26 landfill gas engines in operation on landfill sites around Ireland. The main components of a landfill gas engine as indicated on Figure 1.2 are:

- A **knock-out pot** to remove moisture and particulate matter from the landfill gas to ensure the engine does not become blocked
- A **flow control valve** to control the landfill gas flow to the engine
- **Secondary pre-combustion** treatment of landfill gas may be required depending on the quality of the incoming landfill gas and the design of the engines. This can further remove moisture or landfill gas components that can cause corrosion or abrasion in the engine
- **Gas booster** to ensure a constant landfill gas supply is provided by varying the gas feed pressure using a gas booster
- **Air supply** enters the engine through the air louvres. Engine air-to-fuel ratio controllers adjust this ratio automatically as the methane content of the supply gas changes. Air intake is controlled in some engines by using exhaust oxygen sensors to maintain optimal operating conditions for the engine and maximise power output
- A **flame arrestor and slam shut valve** to avoid flashback of a flame to the fuel feed pipe
- The **engine** and ancillary equipment are usually housed in a container unit that is acoustically designed for noise reduction
- **Control panel** displaying current engine operational parameters, inlet gas analysis and emission analysis (if available)
- **Exhaust and secondary post combustion treatment** so that exhaust air may pass through a silencer to reduce noise emissions prior to release to the atmosphere. In some cases, secondary post combustion exhaust gas treatment may be required where emission limit values are more difficult to achieve for site specific gas qualities
- **Electrical power** (generator & transformer) is produced and used on site or exported to the national grid
- **Back-up flare** to combust any excess landfill gas collected in excess of engines capabilities and/or to manage landfill gas during periods of engine downtime.

This guidance document will focus on emission standards for spark ignition engines only. To maximise the utilisation of landfill gas in the future, smaller capacity spark ignition engines ($< 250 \text{ kWe}$) and micro turbines may be used on Irish landfill sites as landfill gas production reduces. Turbine engines have different emissions characteristics to spark-ignition engines. The impact from micro turbines should be assessed on a site specific basis in consultation with the EPA, however the principles contained within this guidance will also apply to these units.

Figure 1.2: Artist impression of a typical engine arrangement

Note: Optional equipment is subject to landfill gas quantity
 All landfill gas equipment and monitoring equipment should be compliant with ATEX Regulations

1.2 Landfill gas composition

The composition of landfill gas is a major factor in the type and level of emissions following its combustion. Landfill gas is generated by the biodegradation of waste deposited in a landfill. Gas composition varies significantly according to waste type and the time that has elapsed since deposition within the site.

Typically, landfill gas is a mixture of CH₄, carbon dioxide (CO₂), O₂, nitrogen (N₂), hydrogen (H₂), water vapour and trace compounds. The typical percentage range of each of these components is outlined in Table 1.1.

Table 1.1: Landfill gas composition

Landfill Component	Percentage (%)
Methane (CH ₄)	40 to 60
Carbon Dioxide (CO ₂)	35 to 45
Oxygen (O ₂)	1 to 5
Nitrogen (N ₂)	< 1 to 10
Hydrogen (H ₂)	< 1 to 3
Water Vapour (H ₂ O)	1 to 5
Trace Compounds	< 1 to 3

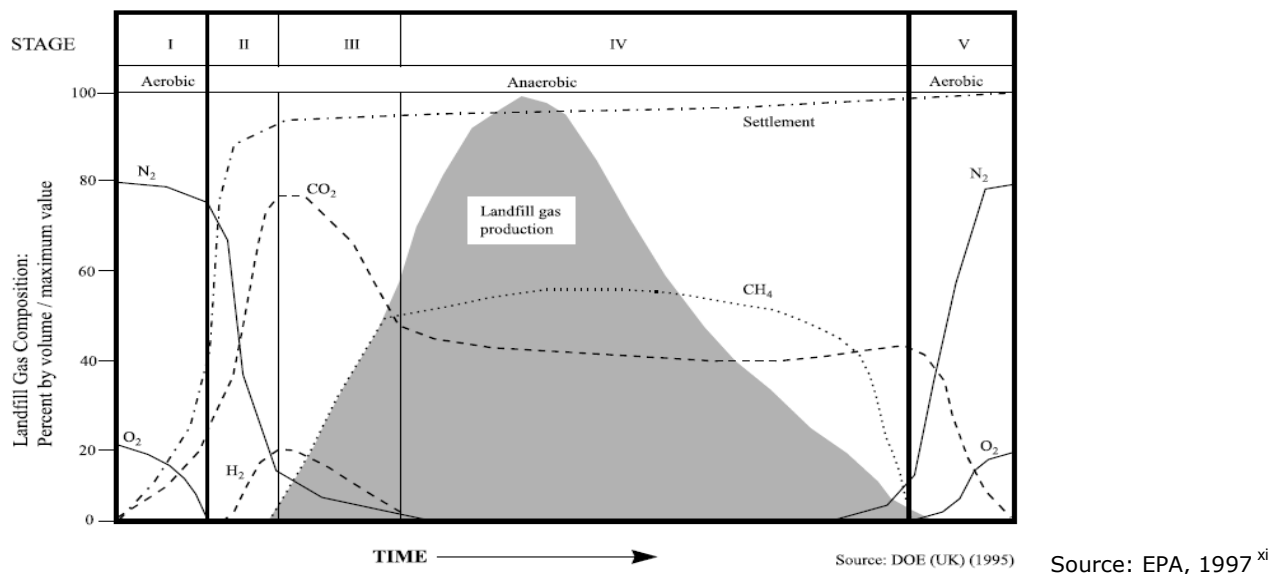
Source: ISWA, 2010^{ix}

Appendix A lists approximately 500 trace compounds^x which can be made up of volatile organic compounds (VOCs), mercaptans, sulphides, etc. These compounds may be volatilised directly from the waste or may be produced from chemical reactions within the waste. Some components can also arise as a result of natural decomposition processes within the landfill, for example, the decomposition of gypsum board to produce hydrogen sulphide (H₂S).

Trace compounds are a component of landfill gas at all sites, however specific compounds and their concentrations are dependent on the composition of the waste, which varies from landfill to landfill. Trace compounds may be present in considerable quantities, in particular if large quantities of particular types of industrial waste have been accepted for disposal.

The rate of gas generation (i.e. waste decomposition) varies throughout the life of a landfill and is dependent on waste types, input rates, depths, moisture content, compaction/density, pH, temperature and the length of time since the waste was deposited^{xi}. The decomposition of waste in a landfill occurs in several distinct phases and landfill gas composition will alter during these phases as shown schematically in Figure 1.3.

Figure 1.3: Changes in landfill gas composition



1.3 Landfill gas combustion

Flares and engines differ in the mechanism of landfill gas combustion and this alters the emissions from each unit. In an engine, combustion occurs in a short-lived pressurised explosion while combustion in a flare occurs over a longer period of time and usually over higher temperatures^{xii}. Combustion destroys the flammable components of landfill gas safely and also mitigates odour nuisance, health risks and other adverse environmental impacts.

Combustion oxidises the combustible components of a fuel. In landfill gas combustion systems, landfill gas is used as the fuel (primarily CH₄) and O₂ (air) is used as the oxidant. The stoichiometric ratio of O₂ to CH₄ for idealised combustion is 9.52:1 with the basic combustion reaction:



If more O₂ is supplied than is required for stoichiometric combustion, then the mixture is termed 'lean and oxidising'. If too much oxygen is provided, the mixture will not burn at a sufficiently high temperature and combustion can be incomplete. If less O₂ is supplied than is needed for stoichiometric combustion, then the mixture is 'rich and reducing'. This will result in incomplete combustion and the formation of intermediate combustion products such as carbon monoxide and non-methane volatile organic compounds (NMVOCs).

In practice, air and landfill gas cannot be mixed perfectly. Excess air is therefore required to ensure that combustion is complete. When estimating the required air supply to a flare/engine the concentration of O₂ in the landfill gas needs to be taken into account. Care is also required to ensure that the addition of excess air does not cool the combustion zone below optimum operating temperature and lead to incomplete combustion. Flares and engines control combustion by automatically adjusting the air intake according to the combustion temperature.

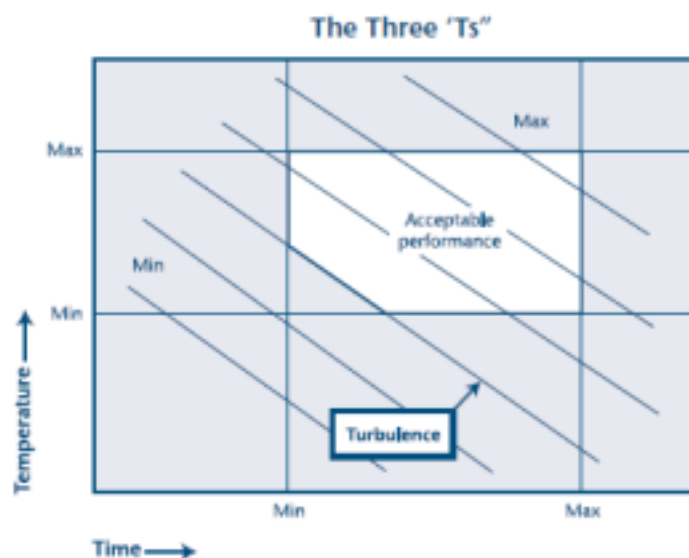
1.4 Factors influencing emissions

Emissions from landfill gas oxidation will vary from site to site due to a number of factors including:

- **Compounds present in the fuel gas:** This was discussed above under *Landfill Gas Composition*
- **Type and design of the equipment used:** Landfill gas flares and engines must be operated at or close to their design capacity. If they are operated outside their design capacity the appropriate emission standards might not be met. This is discussed in more detail in Chapter 3 of this guidance note

- **Operation and maintenance of the equipment:** The operation of a flare and or engine depends on the volume and pressure of fuel gas available. If the pressure or volume of landfill gas reduces it will result in incomplete combustion as flame temperatures may be insufficient. Conversely, if pressure and volume is greater than the design capacity of the equipment incomplete combustion will also occur. The correct operation and maintenance of equipment is important in influencing emissions and is discussed in more detail in Chapters 4 and 5 of this guidance note
- **Combustion conditions:** Factors affecting combustion and emission control include time, temperature, turbulence and oxygen levels. The relationship between time, temperature and turbulence, in order to maintain acceptable performance, is illustrated in Figure 1.4.
- **Combustion temperature** varies with landfill gas methane content and excess air. The temperature falls as the methane content decreases and as the excess air increases, as more air has to be heated from ambient temperature
- **Retention time** is particularly specific to flares. A specific retention time at a required temperature is required for the effective oxidation of hydrocarbons
- **Turbulence** is required to ensure landfill gas and oxygen is thoroughly mixed within a flare or engine to ensure complete combustion
- **O₂**, as discussed in Section 1.3 above, is required to ensure combustion is complete. Flares and engines control combustion by automatically adjusting the air intake according to the combustion temperature. In flares and engines, combustion air is supplied through sets of louvres and the louvre open area determines the flow rate.

Figure 1.4: The Three 'T's': Time, Temperature and Turbulence



(Source: EA, 2002^{xiii})

Local atmospheric conditions can affect air supply, especially in flares. The direction and force of the wind can change the position of the flame within the enclosure and high winds may result in one side of the stack being cold, leading to incomplete combustion and the other side being too hot, leading to higher levels of NO₂ being formed.

1.5 Impacts of emissions

Landfill gas is flammable, toxic, an asphyxiant (in an enclosed closed space at high quantities) and can give rise to other hazards such as vegetation dieback. CH₄ is flammable and explosive at concentrations of 5 - 15% v/v in air.

Whilst the combustion of landfill gas reduces the risk of uncontrolled landfill gas emissions and climate change impacts by converting CH₄ to CO₂ and water vapour, the potential health and environmental impacts of emissions from flares and engine also have to be taken into account.

Table 1.2 outlines the key emissions from landfill gas flares and engines, the reasons for their presence and the potential impacts the emissions may have on health and the environment.

Table 1.2: Key emission and associated potential impacts

Emission Parameter	Reason for Presence	Potential Impact
Carbon dioxide (CO ₂)	Combustion product of methane and other carbon compounds. Present in landfill gas fuel	Harm to flora and fauna Global warming potential Asphyxia
Carbon monoxide (CO)	Product of incomplete combustion due to lack of oxygen, poor turbulence, incomplete mixing, short residence time.	Human health
Nitrogen oxides (NO+ NO ₂).	Combustion product formed from the oxidation of nitrogen in the air, nitrogen in the fuel and /or secondary formation through chemical reaction in flame	Human health Harm to flora and fauna Photochemical air pollution Acidic precipitation
Sulphur dioxide (SO ₂)	Combustion product of oxidation of sulphur-containing compounds	Human health Harm to flora and fauna Acidic precipitation
Particulates	Produced during the combustion processes. Likely to include metal salts from the corrosion of plant and equipment and carbon produced by incomplete combustion	Human health Harm to flora and fauna
Hydrogen chloride (HCl)	Combustion product of chlorinated organic trace compounds in gas	Harm to flora and fauna Acidic precipitation
Hydrogen fluoride (HF)	Combustion product of fluorinated organic trace compounds in gas	Harm to flora and fauna Acidic precipitation
Methane (CH ₄)	Incomplete combustion emitting unburnt fuel gas	Explosion and fire Asphyxia Harm to flora and fauna Global warming potential

(Source: EA, 2002^{xiii} & EA, 2004^{xii})

2. RECOMMENDATIONS ON MONITORING PARAMETERS, FREQUENCY AND ASSOCIATED EMISSION LIMIT VALUES

Waste licences for respective facilities define the air monitoring parameters to be sampled, the frequency these parameters should be sampled and the analysis technique to be used. Emission limit values (ELVs) are also provided for chosen parameters in the outlet emissions.

Monitoring requirements vary from one site to the next. The EPA's decision on these aspects of the licence is taken in the context of all the information provided during the application process. With the issue of a proposed decision (draft licence) the emission limits and monitoring requirements, together with all other aspects of the proposed decision, are subject to an objection period open to the applicant and the public, before a final licence is issued.

Final licences provide for the scope of monitoring (methods and frequency) to be altered with the agreement of the EPA. Limit values are not normally altered unless by way of licence review or other justification to the EPA.

Please note that each waste facility is required to comply with the monitoring conditions stated in the facilities current waste licence. The monitoring recommendations in this guidance note do not replace those stipulated in current waste licences, unless prior agreement has been reached with the EPA.

2.1 Recommended non-continuous monitoring and emission limits

Current waste licences, require non-continuous (periodic) monitoring of flares and engines. Tables 2.1 and 2.2 contain recommendations based on similar guidance by the UK Environmental Agency (EA)^{xiv xv}. The generic recommendations reflect typical flare and engine performance capabilities commissioned before and after December 2003. ELVs and monitoring requirements may however vary on sites (on a case by case basis) subject to site specific risk assessments (SSRA) (refer to Section 2.3).

The generic recommendations set a minimum monitoring frequency for three specified pollutants (NO_x, CO and TOC). The frequency requirements may be higher at new sites.

2.1.1 Flares

Emissions testing recommendations for enclosed landfill flares are as follows:

Table 2.1: Emission testing for enclosed landfill gas flares

Pollutant	Standard method ^a	Technique	Minimum Testing Frequency	Emission Limit Value (mg/m ³) ^b	
				Flare Commissioned before 31 December 2003	Flare Commissioned after 31 December 2003
NO _x ^c	I.S. EN 14792	Extractive sampling & chemiluminescence	Annually	150	150
CO	I.S. EN 15058	Extractive sampling & non-dispersive infra-red analysis	Annually	100	50
Total VOCs	IS EN 12619: 1999 ^d Or IS EN 13526: 2002 ^e	Extractive sampling & flame ionisation detector (FID) analysis	Annually	10	10

^a EPA guidance note AG2

^b These standards are based on normal operating conditions and load (temperature: 0°C (273K); pressure: 101.3 kPa & oxygen: 3 % (dry gas)). Site specific risk assessments may require alternate emission limits to be applied

^c NO_x expressed as NO₂

^d At sites with low total VOC concentrations

^e At sites with low to moderate total VOC concentrations.

2.1.2 Engines

Emissions testing recommendations for landfill gas spark ignition engines are as follows:

Table 2.2: Emission testing for landfill gas spark ignition engines

Pollutant	Standard method ^a	Technique	Minimum Testing Frequency	Emission Limit Value (mg/m ³) ^b	
				Engine Commissioned between 1 January 1998 and 31 December 2005	Engine Commissioned after 31 December 2005
NO _x ^c	I.S. EN 14792	Extractive sampling & chemiluminescence	Annually	650	500
CO	I.S. EN 15058	Extractive sampling and non-dispersive infra-red (NDIR) analysis	Annually	1,500	1,400
Total VOCs	IS EN 12619: 1999 ^d Or IS EN 13526: 2002 ^e	Extractive sampling & flame ionisation detector (FID) analysis	Annually	1,750	1,000

a EPA guidance note AG2

b These standards are based on normal operating conditions and load (temperature: 0°C (273K); pressure: 101.3 kPa; and oxygen: 5 per cent (dry gas). Site specific risk assessments may require alternate emission limits to be applied

c NO_x expressed as NO₂

d At sites with low total VOC concentrations

e At sites with low to moderate total VOC concentrations.

2.2 Recommended continuous monitoring requirements

Recommendations on continuous monitoring of landfill gas flares and engines are outlined in this section.

2.2.1 Flares

The recommended parameters requiring continuous monitoring for landfill gas flares are:

- Flow rate of incoming landfill gas
- O₂ concentration at the inlet
- CH₄ concentration at the inlet
- Combustion temperature in the stack
- CO concentration in the stack
- Continuous burn (run time).

Residence time is typically calculated by theoretical calculations as most installed systems have no facility to measure air intake to the flare or flow rate through the stack. Residence time is not used as a continuous process parameter even though it is a primary criterion for compliant flare operation. It is recommended that residence time calculations are carried out annually over a range of predicted flow rates for the following year.

Continuous monitoring of emission parameters e.g. CO, etc. should also comply with the relevant ELVs for enclosed landfill gas flares outlined in Table 2.1 unless dictated otherwise by SSRAs.

2.2.2 Engines

The recommended parameters requiring continuous monitoring for landfill gas engines are:

- Flow rate of incoming landfill gas
- O₂ concentration at the inlet
- CH₄ concentration at the inlet
- Average combustion exhaust temperature in the respective cylinders
- CO concentration in the stack
- Run time.

CO is used as an indicator of combustion efficiency. However CO readings are subject to drift as a consequence of:

- Need for regular calibration of sensors particularly in engines
- Build up deposits within the engine combustion and valve chambers.

A key consideration is whether or not to use continuous monitoring of CO (or NO_x subject to site conditions) as a primary engine management control function to mitigate the risk of licence non-compliance between services intervals. If operators do not employ continuous monitoring of CO and or NO_x to manage emissions a **SSRA** needs to be provided to the EPA in accordance with Section 2.3 of this guidance note, to justify a deviation from this and to provide alternate monitoring proposals.

Continuous monitoring of emission parameters e.g. CO, NO_x, etc. should also comply with the relevant ELVs for landfill gas spark ignition engines outlined in Table 2.2 unless the SSRA advises otherwise.

2.3 Design certification

The EPA may also consider, as an alternative to emissions testing of parameters, the design certification approach e.g. as operated in Germany. This system assumes that once units are certified at the time of manufacture, then emissions are compliant as long as units are operated and maintained within manufacture's guidelines. Under this model the EPA must have access to approved maintenance schedules and comprehensive maintenance records. This may then negate or reduce the need for stack monitoring.

Design certification may only apply to certain parameters (e.g. typically NO_x, CO or TOC). If site specific requirements for example NO₂, SO₂, PM₁₀ monitoring exists and are not covered by design certification, supplementary emissions monitoring or additional equipment measures will still be required.

TA Luft or similar design certifications are not available for older units. Under these circumstances applications to replace and or supplement emission stack monitoring with regular maintenance programs may be considered by the EPA subject to **SSRA** in relation to unit design and support data provided by respective manufacturers.

2.4 Site specific risk assessments (SSRA)

All sites accepting biodegradable waste are required to undertake landfill gas and emissions monitoring. The nature of the monitoring required is set out in each facility's waste licence. This guidance note sets out the recommended monitoring requirements for landfill gas flares and engines, in terms of monitoring parameters, frequencies, sampling protocols, operation and maintenance inspections, etc. It outlines ELVs for the key emission parameters. It also provides guidelines for the operation and maintenance of flares and engines and appropriate equipment to be used for both flare and engine operation and monitoring.

However, on a case-by-case basis, monitoring practices, operation and maintenance practices, emission limit values, etc., outlined in a facilities waste licence or in this guidance note may not be appropriate to a facility over its lifetime. Under such circumstances a site specific risk assessment (SSRA) should be undertaken by the licensee (or appointed consultant/contractor) to assess if alternative approaches are more appropriate to manage potential environmental conflicts between oxidised emissions and fugitive emissions from the landfill.

The SSRA submission to the Agency should:

- Present the landfill gas management philosophy for the site
- Advise on the actual gas production observations with reference to a calibrated gas prediction curve(s)
- Define historical operational practices and their effects to manage landfill gas quality
- Observed extraction flow rates and emissions (stack and fugitive)
- Provide evidence of historical trends in relation to gas quality
- Extraction flow rates and emissions (stack and fugitive)
- Clearly demonstrate the problem(s) and the proposed solution(s).

The contents of each SSRA should be agreed with the EPA prior to undertaking such an assessment and submitted to the EPA for consideration.

An SSRA can be undertaken at any stage during the lifetime of a waste facility, such as during a waste licence application or review. It can also be triggered based on results of emissions monitoring reported to the EPA. The risk assessment will assess the most appropriate monitoring practices, landfill gas treatment techniques and ELVs on a site by site basis. No changes can be made without the agreement of the EPA.

Where a SSRA identifies unacceptable risks from landfill gas, an emissions improvement programme incorporating the appropriate best practice contained within this guidance and across industry, must be completed as soon as is reasonably practical. Further details on SSRAs are included in Appendix B however the detail of these assessments is outside the scope of this guidance note.

An example of an SSRA carried out on a new cell development of a landfill in Ireland dealt with odour issues in the following way:

A new site accepting municipal solid waste (MSW) for the first time was unable to generate landfill gas of sufficient quality and quantity to allow an enclosed flare to operate in accordance with the site licensed ELVs.

The SSRA determined that the site was in a local topographical depression with adjacent sensitive receptors that would be subject to odour nuisance particularly in frosty weather as a consequence of temperature inversion. The assessment concluded that alternate measures in the short term were required to manage odour nuisance.

The proposed design and eventual solution specified that an enclosed flare be commissioned on site prior to waste being first placed in the cell. The flare and associated equipment was ATEX zone 1 rated.

The blower on the flare was used to extract landfill gas from the cell formation. The landfill gas was then passed through a carbon filter which:

- Initially removed odours when flaring was not possible
- Supplemented flaring by removing odours when flare operation at 1,000°C was not sustainable.

Once continuous flaring at 1,000°C for retention periods > 0.3 seconds was achievable the carbon filter assembly was made redundant and flaring became compliant with licensed ELVs.

This design solution was very effective at mitigating odour nuisance and oxidised landfill gas as soon as it was possible even though oxidation did not take place in accordance with licensed ELVs.

3. EMISSION MONITORING OF FLARES AND ENGINES

3.1 Practical difficulties in monitoring at flares and engines

The techniques used to measure industrial emissions to atmosphere have undergone a series of improvements in recent years. The work the European Standards Authority (CEN) and National Accreditation Boards (like INAB) has opened the way for a standardisation and harmonisation of the methods used to measure emissions.

However, for those with responsibility for monitoring emissions from landfill gas flares and engines, these improvements in technique have had less relevance because of the practical difficulties that arise when attempting to monitor these types of emissions.

While the common techniques used to monitor emissions from an industrial source are broadly suitable for use on landfill gas engines, the monitoring of flare emissions is frequently problematic.

This section outlines the most common problems encountered when monitoring flares. Difficulties in monitoring landfill gas engines are dealt with briefly at the conclusion of the section.



3.1.1 What do we mean by flare emissions monitoring?

Before highlighting some of the problems faced when monitoring flares let us first give a broad description of what constitutes emissions monitoring (or 'stack testing'):

- An EPA waste licence sets ELVs for certain parameters emitted from scheduled emission points. To comply with the licence, the waste operator must monitor the emissions at a defined frequency and report to the EPA to demonstrate compliance
- Most waste licensees will employ specialist contractors to conduct the stack tests. A team will visit the site and gain access to the waste gas stream and will collect samples of the waste gas (for laboratory analysis) and/or use portable equipment to measure flow and pollutant concentrations
- Apart from the periodic assessment of compliance with ELVs, stack tests may be employed for a number of other reasons. Testing can be used to:
 - Verify the data being produced by an installed Automated Monitoring System (AMS)
 - Check emissions to optimise flare performance
 - Simultaneously measure the flare inlet and outlet gases to determine removal efficiency.

The range of parameters that currently require monitoring at EPA waste licensed sites are listed in Table 3.1 below.

Table 3.1: Flare & engine parameters monitored at EPA waste licenced sites

Parameter normally measured using on-site analyser	Parameters normally measured using extractive sampling	Other parameters
Nitrogen oxides (NO _x)	Particulate	Volumetric flow
Carbon monoxide (CO)	Hydrogen Chloride (HCl)	Discharge height
Total Organic Carbon (total VOC)	Hydrogen Fluoride (HF)	Oxygen
Sulphur dioxide (SO ₂)	Speciated organics (TA Luft)	Temperature
	Total Non-Methane VOC (TNMVOC)	

3.1.2 Standard methods for flare monitoring

A waste licence issued by the EPA will typically include a condition such as:

"The licensee shall ensure that:

- (i) sampling and analysis for all parameters listed in the Schedules to this licence; and*
- (ii) any reference measurements for the calibration of automated measurement systems*

shall be carried out in accordance with CEN-standards. If CEN standards are not available, ISO, national or international standards that will ensure the provision of data of an equivalent scientific quality shall apply".

Another typical licence condition permits *"The frequency, methods and scope of monitoring, sampling and analyses, to be amended with the agreement of the Agency."* This allows for some flexibility in design and selection of suitable monitoring procedures.

The monitoring of flare emissions are not covered within the scope of most standard methods because:

- The high temperatures in flares exceed the temperature range of the standard method. Methods are generally validated on the most frequent sources (e.g. incinerator or large combustion plant)
- Monitoring equipment should meet the requirement of the standard method but materials from which the equipment is constructed would sustain damage if exposed to flare temperatures.

The EPA Air Emission Guidance Note AG2ⁱⁱ states that *"Deviation from standard methods would not normally be acceptable to the Agency, and should only occur if the deviation is technically justified, validated and fully documented (where appropriate)".* Method validation is an onerous task for an individual site or their stack testing contractor.

Monitoring contractors should always seek to employ the recommended standard methods when monitoring flare emissions. Deviations from the standard method should be detailed in the monitoring report. The report should also provide information on the equipment that was used and its suitability to the application (e.g. high temperature sampling probes).

3.1.3 Ensuring that flare monitoring is representative of the emission

When addressing the question 'Are the monitoring results representative of the emission?' there are two main factors to consider:

- When the monitoring was conducted
- Where the monitoring was conducted.

Most waste licences issued by the EPA for non-continuous monitoring state that *"No 30-minute mean value shall exceed the emission limit value"*. To ensure monitoring takes place over the most representative 30-minute period can be particularly challenging for the following reasons:

- By its nature the amount and composition of landfill gas will vary over time. As a consequence the flare off-gases can vary
- Some flares operate infrequently because there is insufficient methane, therefore an operator may need to alter extraction management to ensure sufficient gas is available on the day that monitoring is scheduled

All forms of environmental emission monitoring must be conducted at a point in the waste stream that is post-abatement and which does not hamper the monitoring process (staff and equipment). The difficulties with flare monitoring are:

- Flaring is itself an abatement process and monitoring of a flare emission should be conducted at a point above the flame otherwise the results will not be representative
- Many enclosed flares are designed so that the flame height is almost equal to the stack height. This means the sampling plane must be located adjacent to the release point (stack top)

- Monitoring should be conducted at a point where the gas stream is homogeneous i.e. there is no spatial variance of the pollutant at the sampling plane so that the positioning of the sampling probe within the stack does not affect the measurement result. In the case of flares, the proximity of the flame to the sampling location makes it difficult to ensure homogeneity. The standard test to assess the homogeneity of a gas stream (I.S. EN 1525 (BS 2009)) involves the use of two monitoring kits
- Many flares have sample lines permanently installed as part of an AMS. While it is common for these lines to be used by stack testing contractors during periodic monitoring, these lines are not normally temperature controlled and their integrity cannot be assured.

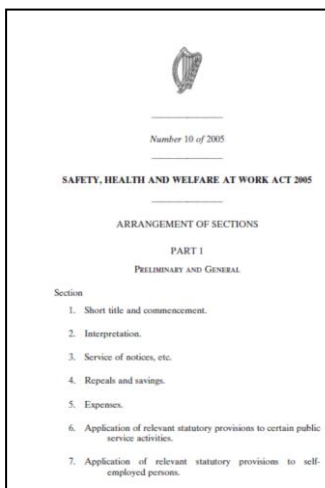
3.1.4 Monitoring of landfill gas engines

The monitoring of landfill gas engines rarely presents the same level of difficulty to that of flares. Issues that may arise in the monitoring of engines include:

- Engine exhausts are typically located at height and without the presence of a permanent sampling platform
- Engine exhaust gases, while not as hot as flares, may present a high temperature risk to staff and equipment
- The timing of the monitoring event may impact on the results obtained because of the variability of the landfill gas composition
- Engine emissions are characterised by high levels of nitrogen oxides and the range of monitoring techniques employed need to take account of this
- Engines may have permanently installed sample lines as part of an AMS. These lines are not normally temperature controlled and their integrity cannot be assured.



3.2 Health and safety



The Safety, Health and Welfare at Work Act, 2005^{xvi} is the primary legislative platform for ensuring worker safety in Ireland. Employers are responsible for creating and maintaining a safe and healthy workplace and employees must undertake their work in a manner that does not endanger themselves or their colleagues. The General Application Regulations 2007 and in particular Part 4^{xvii} which deals with working at height has particular relevance for those involved in emissions monitoring. The Health and Safety Authority (HSA) monitors compliance with legislation in the workplace and can take enforcement action (including prosecutions).

A general condition in waste licenses issued by the EPA is “*The licensee shall provide safe and permanent access to all on-site sampling and monitoring points and to off-site points as required by the Agency*”.

The following is a list of reasons why the monitoring of flares is particularly challenging when it comes to ensuring the health and safety of monitoring staff:

- Sampling ports are located toward the top of the stack and access involves working at height
- Permanent working platforms that provide access to sample ports are not commonly available on flares
- In windy conditions, the heat plume can be forced laterally over the edge of the stack resulting in extreme temperatures in the vicinity of the sampling ports
- Equipment and staff can be exposed to hot surfaces at the external walls of non-insulated stacks

- Explosives atmospheres in the vicinity of a flare present a danger to sampling staff and may prohibit the use of commonly used monitoring equipment. Many licences have a condition that requires landfill gas monitoring equipment to be certified as intrinsically safe. While it may not be explicitly stated, this condition is generally intended to refer to monitoring equipment that is installed within buildings, (e.g. for the protection of staff in site offices). Equipment used for emissions testing is not commonly available in an intrinsically safe form, so if this equipment is sited in an area of poor ventilation then the risk of explosion must be addressed.

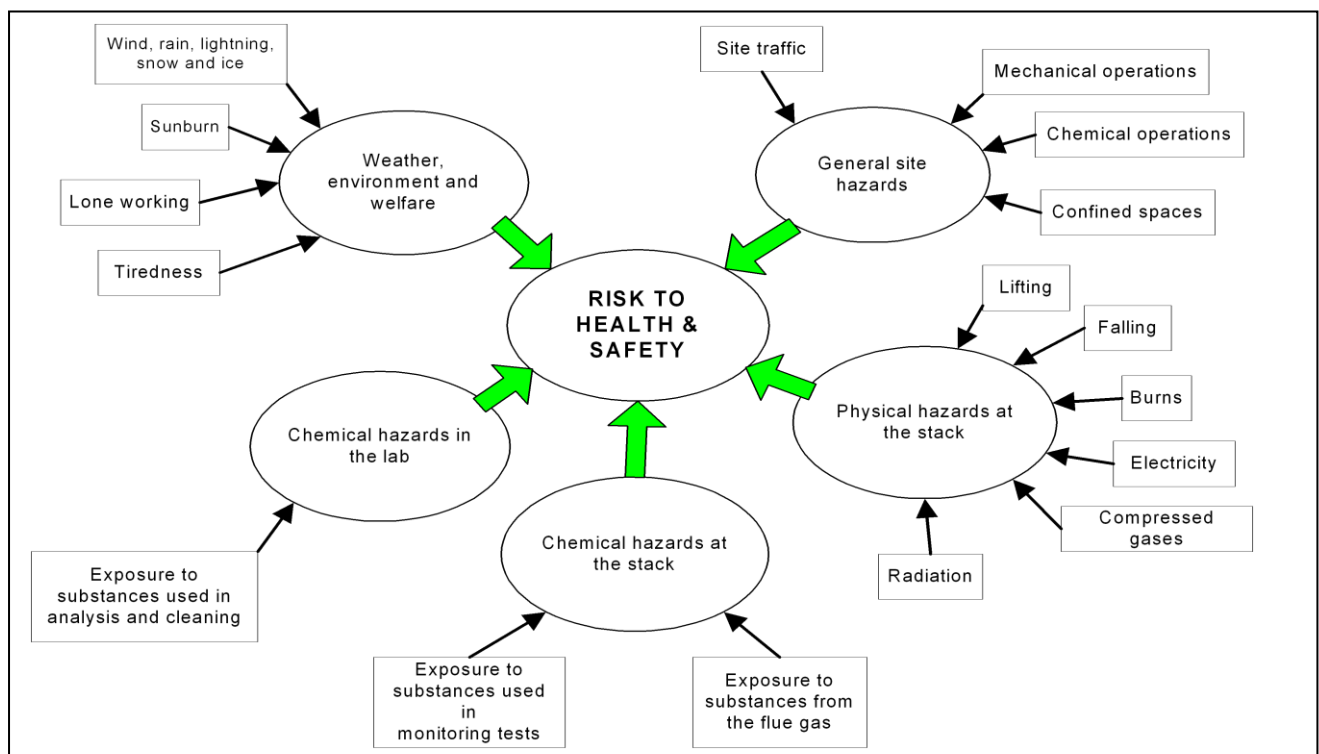
The health and safety aspects of flare and engine emission testing must be given priority. The importance of monitoring environmental emissions should never be placed ahead of the health and safety of personnel whose job it is to conduct the monitoring.

A health and safety risk assessment process must always precede flare and engine testing. It is the responsibility of the landfill operator and the monitoring contractor to ensure the risk assessment process is appropriate for the protection of all personnel.

Stack testing staff **MUST** not access sampling ports that are located at (or near) the top of the flare stack during flare operation. A lock-out system must be put in place to ensure that flare remains off and cooled down prior to staff accessing the sampling ports.

Figure 3.1 shows some of the many hazards that need to be considered when carrying out stack testing. The risks associated with these hazards can be managed through the application of appropriate control measures along with proper staff training, the use of suitable Personal Protective Equipment (PPE) and adherence to risk assessment methodologies.

Figure 3.1: Hazards to be considered when undertaking stack testing



While it is beyond the scope of this guidance document to deal at length with the topic of health and safety, Table 3.2 sets out some fundamental rules which should be adhered to when testing landfill gas flares and engines.

Table 3.2: Flare and engine testing – health and safety fundamentals

Health and Safety Requirements	
1	The provision of safe monitoring facilities should be an inherent part of the design, costing and construction of flares and engines
2	Existing flares and engines should be assessed for compliance with the requirements of EPA guidance note AG1 and related health and safety guidance. Monitoring should not proceed until all parties are satisfied that the risks are low as reasonably practical
3	The time and support structures necessary to do the job safely must be factored when the stack testing contractor is costing the monitoring programme
4	Testing of flare emissions should only be undertaken by experienced stack testers with appropriate qualifications in emissions testing and health and safety risk assessment
5	Should any person, stack tester, licensee or regulator, identify an unacceptable risk then monitoring should be immediately suspended pending an assessment by trained personnel
6	Inadequate safety provisions should be communicated immediately to the licensee and where necessary to the EPA

For further sources of guidance on health and safety refer to:

- EPA Guidance Note on *Site Safety Requirements for Air Emission Monitoring (AG1)*ⁱ
- EPA *Air Emission Monitoring Guidance Note (AG2)*ⁱⁱ
- Source Testing Association (STA) - *Risk Assessment Guide: Industrial-Emission Monitoring*^{xviii}

3.3 Sample location, port and facilities

The landfill operator is responsible for ensuring that the necessary facilities are in place for emissions monitoring at all reasonable times. Proper and safe sampling facilities will benefit the licensees monitoring programme as well as the EPA's independent monitoring programme.

The EPA guidance note AG1 *Guidance Note On site Safety Requirements for Air Emission Monitoring*ⁱ details the facilities required to conduct emissions monitoring. The following sections summarise those requirements in the context of flare and engine monitoring.

When making decisions on sampling location and sampling ports, AG1 requires that the licensee identify the air emission categories which require measurement from the following list:

- Particulates (or dust) - Accurate sampling of particulates requires that the waste gas flow is laminar (free from turbulence) and that the sample is collected isokinetically at a pre-selected number of points across the sample plane. The port(s) size should be a 4 inch British Standard Thread (BSP) fitting with cap. Ports should be located downstream of final abatement and away from sources of low disturbance (ideally 5 duct diameters). Sampling ports should not be located in confined spaces where it could be difficult to manoeuvre sampling probes
- Volume flow (or stack gas velocity) – Location and positioning of sampling ports are similar to the requirements for particulate monitoring (above). The port size should be a 1 to 1½ inch BSP fitting with cap
- General gaseous pollutants - Sampling ports must be downstream of the abatement system and the stream should be homogeneous across the area of the sampling plane.



It is also recommended that the operator checks with their monitoring contractor that ports are compatible with monitoring equipment.

Where the landfill operators can demonstrate that AG1 recommendations on the location and installation of sampling ports is not feasible on the grounds of cost or that modifications to standard methods need to be employed for reasons of health and safety, then the following alternatives may be agreed with the EPA:

- A derogation from the need to monitor parameters that require the use of manual sampling trains (USEPA5 type) on grounds of an environmental risk assessment
- Use of in-situ sampling probes to which the monitoring contractor can connect their sampling lines to sample stack gas
- Use of in-situ sampling probes and sampling lines to which the monitoring contractor can connect their analysers (unheated lines should not be used)
- Determination of exhaust flow by measurement of landfill gas flow at inlet and calculation.

3.3.1 Access to sample ports

AG1 contains the EPA recommendations for access to sampling ports. While alternative approaches can be appropriate, it is the responsibility of the licensed site and the monitoring contractor to conduct a safety risk assessment and ensure:

- Access to the sampling location should be via a secure stairway, permanent ladder or gangway
- A working platform that provides space for handling of equipment must not be less than 5 m²
- Open sides of platforms must be fitted with safety handrails and kickboards
- Sampling locations are not sited in areas of excessive heat or poor ventilation

Where the landfill operators can demonstrate that installation of permanent structures are not feasible on the grounds of cost or are unnecessary because of the type of monitoring that is required, then the following alternatives may be appropriate (Subject to risk assessment):

- Temporary platform with secure ladders – inspected by a competent person and scaff-tagged (used for equipment set-up and probe insertion, not as a working platform).
- Sampling ports on engines are frequently accessible from the roof of the engine enclosure and safety handrails and kickboards may be installed as a permanent feature
- The provision of lifting apparatus to raise equipment to the sampling platform may be considered on a case by case basis although a lot of the monitoring conducted at flares and engines can be achieved with equipment that is located at ground level

When a working area is located at ground level then the area should be cordoned off to protect monitoring equipment and staff from the dangers of moving vehicles.

All work equipment used for working at height should be inspected in accordance with the relevant health and safety legislation (this includes sampling platforms, scaffolding, ladders, work restraint systems and others).

3.3.2 Power supply

A 110 V power supply should be provided at the point of monitoring. External power points should be weather proofed. Extension cables carrying 220 V should never be used.

3.3.3 Stack identification

All licensed stacks should be clearly labelled at the sample port. Labels should be weatherproof and identify the emission point as per its designation in the site's waste licence. Refer to AG1 for an example of an emission point label.

3.3.4 Person in charge

It is a standard requirement of all waste licences that a suitably qualified and experienced manager (person in-charge) shall be present at the facility at all times during its operation.

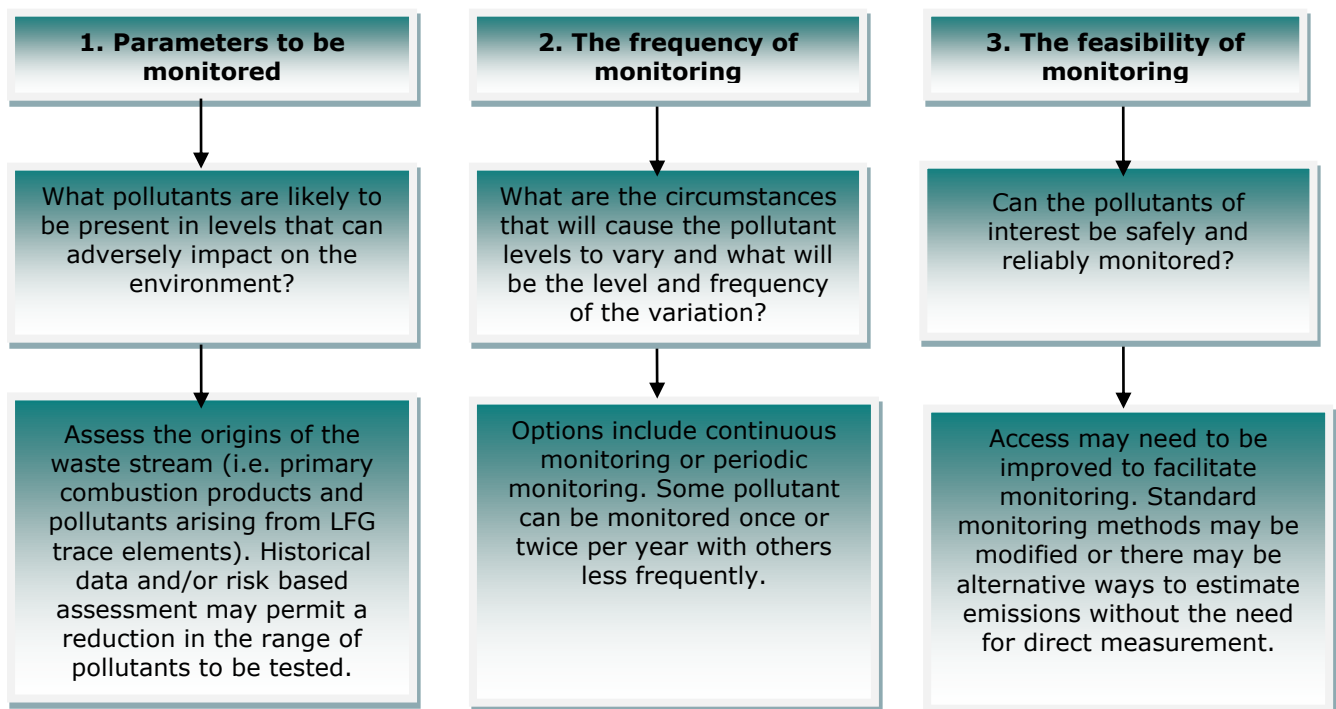
In the context of flare and engine monitoring, it is particularly important that the person in charge takes an active role in the design and completion of the monitoring programme for the following reasons:

- The health and safety issues that are associated with the monitoring - The Site Safety Officer must ensure that the risks are as low as reasonably practical and take an active part in the Health and Safety Risk Assessment that precedes all monitoring activity on the day of the monitoring event
- The need to ensure emissions are representative during the monitoring event - To assist in the collation of information that supports the monitoring data of long-term operating conditions (e.g. process status, data on input gas quality, abatement plant status and AMS data).

3.4 The monitoring plan (including site review & site specific protocol)

Each waste licence permits the scope of monitoring to be modified over time with the agreement of the EPA. The scoping process should be risk based and reflect the flare/engine emissions potential to generate an adverse environmental impact, (refer to Section 2.4 which deals with Site Specific Risk Assessment). Figure 3.2 gives an example of the variables that must be considered when deciding the scope of monitoring at a landfill flare/engine. A person that is experienced in emission monitoring should have an input at this stage so that all parties are aware of what is possible in terms of monitoring.

Figure 3.2: Scope of flare/engine monitoring

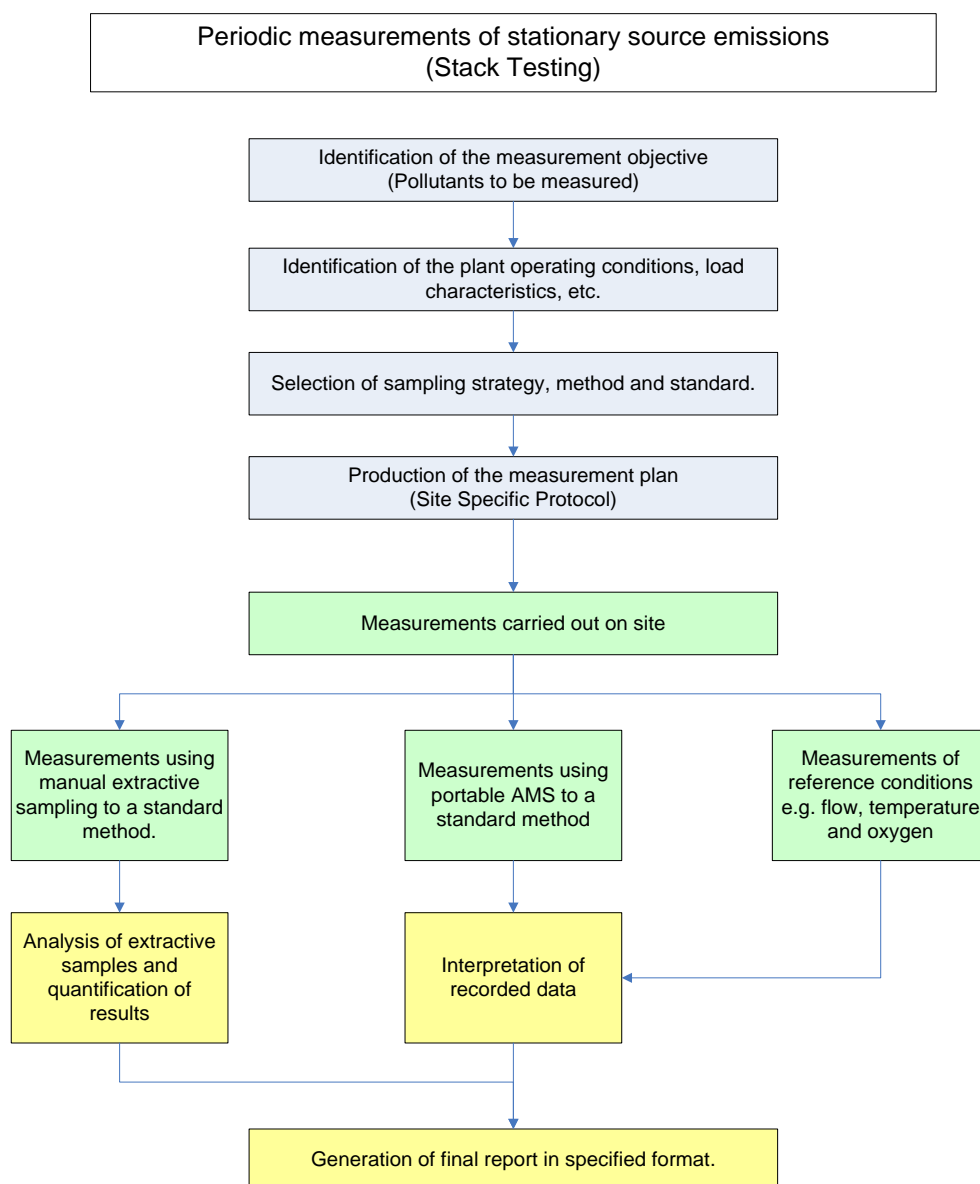


Once the scope of monitoring has been defined the need to plan the monitoring programme is fundamental. In the case of periodic monitoring, the EPA guidance note AG2 requires that the planning process that precedes emissions monitoring should include the following:

- A site review – A reconnaissance visit by the emission testing team to collect information on safety, site facilities and the process (Refer to Appendices E & F)
- A Site Specific Protocol (SSP) – A monitoring plan prepared by the emission testing team for the agreement of the site operator. This defines the methods and techniques that will be employed and their performance in the required range (i.e. ELV)
- Health & Safety risk assessment – prepared by the contractor for the specific site.

Figure 3.3 lists the generic sequence steps that is involved in the periodic measurement of stationary source emissions.

Figure 3.3: Sequence of steps – Flare/Engine monitoring process



Source EPA, 2007ⁱⁱ

The following is a list of some issues that are relevant to flare and engine monitoring in particular:

- Access to flare monitoring points (and to a lesser extent engines) may require the involvement of other contractors (e.g. scaffolders and mobile elevated work programme (MEWP) operators). These contractors have a key role to play in the safety of the monitoring programme and should be involved at the site review stage. Issues that relate to safety should never emerge on the day of the stack tests
- The site review will need to collate additional information that is not normally a feature of standard industrial source monitoring. This information may include:
 - Flame height within stack
 - Temperature of external wall (avoid risk of burns to staff or equipment)
 - The times that landfill gas supply is suitable for monitoring
 - The stability of the flame
 - If an in-situ sampling probe or line is to be used then the contractor may need to inspect probe and line during the review to ensure that they are in good condition and compatible with monitoring equipment
 - Can volume flow measurements (or estimates) be made at the same time as pollutant concentration measurements?
- A modification to a standard method (if necessary on the grounds of safety) will have the potential to increase the uncertainty of the measurement. All reasonable efforts should be made to estimate the uncertainty of measurement and this should be defined in the SSP. The STA has produced a guidance note for members on *Assessing Measurement Uncertainty in Stack Monitoring* with associated excel spreadsheets for calculating uncertainty
- Any modification to a standard monitoring method must be documented in the site specific protocol and in the monitoring report.

3.5 Pollutants & measurements techniques

The most frequently occurring pollutant ELVs for flares and engines that appear in Irish waste licenses are:

- Combustion gases
- Particulates
- Acid gases
- Speciated organics (TA Luft classes)
- Total Organic Carbon (as C).

Further details on methods that the EPA recommends for the measurement of these pollutants can be found in EPA guidance note AG2. This section provides a summary description of the techniques commonly employed for the periodic measurement of these pollutant releases and also measurements that are required on the landfill gas stream prior to abatement/combustion.

The following section is intended primarily for those who are less familiar with stack testing but who have a role in deciding the levels of testing required (e.g. operators, regulators).

3.5.1 Pollutants released to atmosphere

Table 3.3 provides general information on the measurement techniques for each pollutant and a comment on how difficult these techniques are to employ at flare and engine emissions. The difficulty score takes into account safety, protection of equipment and reliability of measurement. The difficulty has been scaled as follows:

- Very difficult/impossible [3]
- Possible with good planning [2]
- Straight forward [1].

The degree of difficulty ascribed will vary from site to site and should be taken only as an indication.

Table 3.3: Measurement techniques for pollutants and associated difficulty

Determinand	Measurement techniques	Flare monitoring difficulty	Engine monitoring difficulty
Combustion gases	These gases include SO ₂ , Oxides of Nitrogen (NO _x as NO ₂) and CO. They are most often measured using portable continuous analysers. Heated sampling lines and gas conditioning (moisture removal) must be used in tandem with analyser. Heat resistant probes are likely to be required. The sampling equipment can be sited at a distance from the sampling port	2	1
Total particulate	Particulate (dust) needs to be sampled isokinetically, failure to do so will bias the collected sample in favour of a particular size fraction. Samples are collected on a pre-weighed filter followed by gravimetric analysis. Sampling equipment and staff would normally be positioned at the sample port but this approach is not possible when ports are located near the flare release point (due to extreme temperatures)	3	2
Inorganic gases	The techniques for substances like hydrogen chloride (HCl), hydrogen fluoride (HF), Total Acids and ammonia (NH ₄) usually involve sampling into impingers that contain a suitable absorbing solution. Many of the standard methods employ laboratory analyses by ion chromatography. Sampling equipment must be positioned at the sample port, (options may exist to locate the sampling train at a distance from the port by using heated sampling lines and dilution methods but these are not tried and tested)	3	2
Total Organic Carbon (TOC)	Portable Flame Ionisation Detection using a heated filter and sample line. The analyser is calibrated with Propane, (no other calibration gas is acceptable). The sampling equipment can be sited at a distance from the sampling port	2	1
Organic gases (speciated)	The common technique employs sample collection on to a sorbent tube and laboratory analysis by Gas Chromatography Mass Spectrometry (GCMS). Sampling equipment must be positioned at the sample port, (options may exist to locate sampling train at a distance from port by using heated sampling lines and dilution methods to reduce gas sample temperatures to below 40°C – maximum temperature suitable for sorbent tubes)	3	2
Gas flow rate (Nm ³ /hr)	Volume flow (velocity) is commonly determined using a Pitot tube and differential pressure meter (manometer). Temperature and pressure must be measured for correction of the flow result to NTP. Sampling equipment and staff must be positioned at the sample port. Flare temperatures are above the range deemed suitable for pitot tube methods and options may exist to measure landfill gas inflow instead, (for details refer to appendix C of EA guidance on LF engine monitoring ^{xv})	3	2
Oxygen (%)	Portable oxygen analysers are used in tandem with heated sampling lines and gas conditioning. The sampling equipment can be sited at a distance from the sampling port	2	1

Determinand	Measurement techniques	Flare monitoring difficulty	Engine monitoring difficulty
Moisture (%)	Extractive sampling through a heated line into cooled impingers and silica gel with gravimetric analysis. Sampling equipment must be positioned at the sample port.	3	2

It must be noted that Table 3.3 only addresses the most common techniques. There are alternative techniques that can be employed such as Fourier Transform Infrared Spectrum (FTIR) that can be used to measure a broad range of gaseous species such as HCl, HF, NH₃ and CH₄, and the EPA may require such methods to be used in specific cases.

3.5.2 Gases measured in landfill gas prior to abatement/combustion

All waste licences require the measurement of gas composition in the landfill gas streams entering a flare or engine. These measurements provide information on the quality of the landfill gas for combustion but they may also be used to determine levels of fluorine, chlorine and sulphur and act as an alternative to the measurement of HF, HCl and reduced sulphur in the flare or engine release gases.

Table 3.4 provides general information on the common techniques employed at combustion plant inlets. No difficulty score has been ascribed because the measurement/sampling exercise is generally free from safety or equipment damage considerations due to the monitoring port being located at ground level. However, the sampling ports are frequently located in hazardous environments therefore intrinsically safe equipment is recommended where available.

Table 3.4: Common techniques for inlet gas measurement

Determinand	Measurement techniques
Methane (CH ₄)	Direct reading IR/FID/thermal conductivity analyser. Normally measure continuously with installed AMS
Carbon dioxide (CO ₂)	Direct reading IR analyser. Normally measure continuously with installed AMS
Oxygen %	Oxygen analysers. Normally measure continuously with installed AMS
Total sulphur	Colour indicating tube is most convenient but less reliable than standard method
Total Chlorine	Colour indicating tube is most convenient but less reliable than standard method (e.g. USEPA method 26a)
Total fluorine	Colour indicating tube is most convenient but less reliable than standard method (e.g. USEPA method 26a).

3.6 Quality control and assurance

Waste licenses issued by the EPA contain a variety of conditions that relate to the quality of a site's environmental monitoring programme. Examples of the type of licence conditions are as follows:

"The licensee shall carry out such sampling, analyses, measurements, examinations, maintenance and calibrations as set out below and as in accordance with Schedule Control & Monitoring, of this licence:

- Analysis shall be undertaken by competent staff in accordance with documented operating procedures.*
- Such procedures shall be assessed for their suitability for the test matrix and performance characteristics determined.*

- Such procedures shall be subject to a programme of Analytical Quality Control using control standards with evaluation of test responses.
- Where analysis is sub-contracted it shall be to a competent laboratory.

The licensee shall carry out such monitoring and at such locations and frequencies as set out in Schedule D of this licence and as specified in this licence

Monitoring and analysis equipment shall be operated and maintained in accordance with the manufacturers' instructions (if any) so that all monitoring results accurately reflect any emission, discharge or environmental parameter.

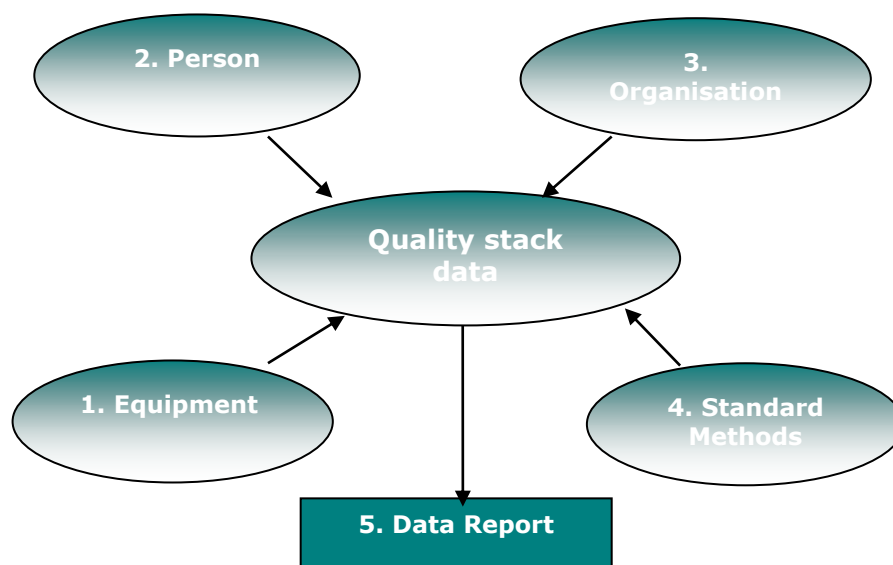
All persons conducting the sampling, monitoring and interpretation as required by this licence shall be suitably competent".

When a landfill operator is selecting a contractor to conduct emissions monitoring of flares and engines they should look for evidence of:

- Prior experience in testing at flares and engines
- Best practice in project planning (refer to Section 2.6)
- Best practice for the generation of quality emission data (monitoring accreditation).

The schematic in Figure 3.4 identifies the main elements that influence the quality of flare and engine emission data. In the following sections, we discuss each of these elements in turn, the various certification/accreditation schemes that relate to the emission testing business and the important subject of measurement uncertainty. For a more detailed treatment of these topics the reader should refer to the EPA guidance document AG2ⁱⁱ.

Figure 3.4: Factors that Affect the Quality of Emission Data



3.6.1 Monitoring equipment

The equipment that is used in the course of flare and engine emissions testing includes portable analysers, gas sampling trains and peripheral equipment for the measurement of parameters like temperature pressure and flow rate. If any of this equipment should be inaccurate or malfunction then this can lead to an erroneous assessment of the emission, with a mistaken appraisal of licence compliance or environmental impact. Monitoring equipment should be:

- **Fit for purpose** - It must meet the specifications of the standard method being employed and be suitable for the application. Equipment manufacturers should also be able to provide information on the suitability of their equipment for high temperature flare monitoring and any specific additional equipment/parts required to ensure representative monitoring is possible.
- **Subject to appropriate maintenance and calibration** - Portable analysers will normally be calibrated on-site (before and after the monitoring event). Other equipment like gas meters, temperature probes will be calibrated with a frequency defined by the monitoring organisations Quality Management System (QMS)
- **Independently certified** (where applicable) - Schemes for the product certification of stack monitoring equipment exists in the UK (MCERTS Product Certification) and in Germany 9TUV Approved).

Flare temperatures are above the range of many commonly used items of stack testing equipment and steps must be taken to avoid equipment damage that would lead to inaccurate results. Special arrangements for flare testing may include:

- Use of high temperature ceramic probes
- Cooling coils to reduce sample gas temperature
- Measurement of sample gas temperature prior to entering temperature sensitive monitoring equipment.

3.7 Standard methods

Standard reference methods are in many ways the 'first stop' when it comes to designing an atmospheric emissions testing programme. Standard methods are developed by committees at both European and international level, for example Comité Européen de Normalisation (CEN) technical committee on Air Quality (CEN TC264) and International Standards Organisation technical committee on Air Quality (ISO/TC 146). An increasing number of methods are being developed by the European standards authority (CEN) and these are the standards most frequently required by the EPA for use in Ireland. The manner in which the monitoring method is defined in the waste licence can vary from site to site as follows:

- Some licenses may be prescriptive and quote a particular standard method to be employed (e.g. IS EN 13284 for particulates)
- Some licenses stipulate the monitoring method in generic terms (e.g. Isokinetic/gravimetric or sorbent tube/GCMS)
- Some licenses require that methods are agreed with the EPA following license issue

In all cases, the licensed operator and their monitoring contractor should have regard to the current listing of EPA preferred methods, (refer to guidance document AG2ⁱⁱ). The methods that are most applicable to flares and engines are listed in Table 3.5 below.

Table 3.5: Standard methods applicable to flares and engines

Determinand	Technique	Preferred Standard method
Nitrogen Oxides (as NO ₂)	Portable analyser, chemiluminescence.	I.S. EN 14792
Carbon Monoxide (CO)	Portable analyser, Non Dispersive Infra-Red (NDIR).	I.S. EN 15058
Total Particulate	Isokinetic sampling onto filter with gravimetric analysis.	IS E.N. 13284-1 (low range) or ISO 9096 (high range)
Hydrogen fluoride (gaseous)	Sampling into alkali bubbling solutions with analysis by IC or ISE.	ISO 15713
Hydrogen Chloride (gaseous)	Sampling into deionised water with analysis by IC or ISE.	I.S. EN 1911
TA Luft Organics Class I, II, III. (speciated organics)	Sampling charcoal with analysis by GC.	I.S. EN 13649
Total Organic Carbon (as C) <small>Note 1</small>	Portable analyser Flame ionisation detection.	I.S. EN 12619
Gas velocity and temperature (Volumetric flow)	Pitot tube/differential pressure gauge and thermocouple.	I.S. EN 13284 - 1 or ISO9096
Oxygen	Portable analyser (various).	I.S. EN 14789
Moisture (water vapour)	Sampling into condenser unit and gravimetric analysis.	I.S. EN 14790

Note 1: Different waste licences refer to Total Organic Carbon (TOC) (as C) as TOC, VOC, Total VOC, Hydrocarbons and Total Hydrocarbons.

None of the organisations that generally produce standard methods (e.g. CEN, ISO, USEPA, etc.) have produced methods that are specific to flare and engine monitoring. Despite this, flare and engine monitoring reports will often quote standard methods from these sources as being employed in the monitoring programme.

It is important that the monitoring report identifies: 1) the scope of the method relative to the application and 2) any deviations from the method due to problems of access or safety. A monitoring report that makes a simple reference to a standard method without further elaboration may imply a level of conformance to that method that was not the reality.

3.8 The monitoring organisation

The monitoring organisation should have in place a quality management system (QMS) which addresses the management and technical aspects that affect the quality of the service they provide to the landfill operator. These aspects will include:

- Accommodation and environmental conditions at the sampling location
- Test methods and method validation
- Estimation of uncertainty of measurement
- Test traceability and participation in proficiency testing
- The sampling and on-site measurement process – including site review, risk assessment, site specific protocol, sample handling, analysis and reporting.

The monitoring of landfill flare and engine emissions represent a sub-set of the environmental testing business in Ireland. Organisations that provide this testing service will typically be involved in the monitoring of industrial emissions at IPPC licensed sites also.

It is recommended that the monitoring contractor make provision in their QMS that addresses the equipment, staff training and protocols necessary to deal with the specifics of flare and engine testing.

3.9 Monitoring accreditation

The UK MCERTS performance standard for organisations^{xix} is an example of an ISO 17025^{xx} based accreditation scheme for stack testing that is becoming increasingly prevalent in Ireland. This performance standard supplements the requirements of ISO 17025 in specific areas of relevance to stack testing. Currently the EPA and the Irish National Accreditation Board (INAB) are acting to establish a comparable scheme in Ireland.



A listing of laboratories that are accredited to the ISO 17025 standard in Ireland is available from the INAB website. A listing of stack testing organisations that are UKAS accredited (including some based in Ireland) to the MCERTS performance standard is available from the UKAS website.

In 2011, the Board of the EPA approved a recommendation from the Office of Environmental Enforcement that air emissions monitoring at all EPA licensed sites must be completed by ISO17025 accredited contractors from January 1 2014. Where monitoring is carried out by non-accredited laboratories, the subsequent report will not be accepted by the EPA if the sampling is carried out after January 2014.

This requirement will apply to the monitoring of emissions from flare and gas engine stacks at landfill sites.

3.9.1 Monitoring personnel

Staff that conduct flare and engine monitoring must ensure the competent use of equipment, adherence to agreed protocols and safe completion of the project. The monitoring contractor must assign staff that have the experience, training and qualifications appropriate to the task and this should form part of the organisation's QMS.

A person's competency in stack testing may be assessed by interview, examination, observation on-site or consideration of their experience (e.g. a log of all site visits and measurement types). Many Irish contractors rely on the UK EA MCERTS scheme for personnel certification^{xxi xxii} as a means to demonstrate staff competency. The MCERTS scheme is based on the following competence levels:

- Trainee – Entry level staff that must not conduct stack emission monitoring unless supervised. All trainees must be trained in risk assessment and hazard identification before advancing to the next level

- Technician – Intermediate level, the technician should display a basic competence in emissions testing and be capable of conducting a risk assessment and site review under the supervision of a team leader
- Team leader – These are staff that have the primary responsibility for the management of an emission monitoring campaign. The team leader should display competence in areas which include; monitoring standards, calculation of results, analytical techniques, sample handling, limit of detection, abatement systems, choice of sampling location, design and implementation of a measurement campaign, developing site specific protocols, calculating uncertainty and a detailed knowledge of health and safety appropriate for self-protection and the protection of junior staff.

The MCERTS scheme for personnel certification is not mandatory in Ireland but it is a common and useful gauge of competency that landfill operators may employ when selecting a contracting organisation.

Testing of landfill engines and particularly the testing of flares rests at the more difficult end of the emissions testing profession and therefore should only be undertaken by staff with a high level of experience.

3.10 Uncertainty

In relation to uncertainty of measurement the EPA guidance note AG2 requires that the measured value is shown to be 'fit for purpose' by taking account of the uncertainty of measurement and assessing its impact on the likelihood of non-compliance. In other words, the closer the measured value is to the environmental limit the greater the need to define the uncertainty. The calculation of measurement uncertainty involves a process which:

- Defines the measurement steps
- Identifies the sources of uncertainty in each step
- Quantifies those uncertainties
- Combines the uncertainties
- Expressing uncertainty within a known confidence interval (normally 95%).

International Standards Organisation (ISO) and the International Electrotechnical Commission (IEC) provide a guide to measurement uncertainty^{xxiii}. Guidance can also be found in the BREF reference document on the *General Principles of Monitoring*^{xxiv} as well as the STA publication *Assessing Measurement Uncertainty in Stack Monitoring* which contains guidance excel spreadsheets for calculating uncertainty.

Uncertainties are quoted in Table 3.6 below for the three parameters that are most commonly measured at flares and engines. These uncertainties are deemed to apply when the monitoring team have fulfilled all aspects of the particular standard method.

Table 3.6: Uncertainties for Common Standard Methods

Determinand	Reference	Quoted uncertainty
Nitrogen oxides (NO ₂ as NO _x)	BS EN 14792: 2005	<10 percent of full scale deflection
Carbon monoxide (CO)	BS EN 15058: 2006	<10 percent of full scale deflection
Total volatile organic compounds (TVOC)	BS EN 12619 :1999 BS EN 13526 : 2002	0.28-0.42 mg/m ³ for a concentration range of <1 to 15 mg/m ³

The true uncertainty of measurement of flare emissions can be higher than comparable tests performed at industrial sources (refer to Table 5.4 of EA guidance on flare monitoring ^{xiv}). This is for reasons associated with sampling position and the modifications to equipment and methods that will often be necessary to conduct the work safely. Notwithstanding this fact, the approach to the estimation of uncertainty should be clearly stated in the monitoring report. It is not acceptable to quote a measurement uncertainty without a description of how that value was derived.

3.11 Reporting

The EPA has a legal obligation to provide public access to information in relation to the enforcement of waste licenses.

Reports that are received by the EPA are placed on the public file. The report must provide the non-technical reader with concise and unambiguous information about the emission points that were tested and an assessment of compliance with limit values (where applicable). It should also provide the licence inspector with both summary information and the supporting technical detail to demonstrate the probity of the measurement process and the reliability of the results.

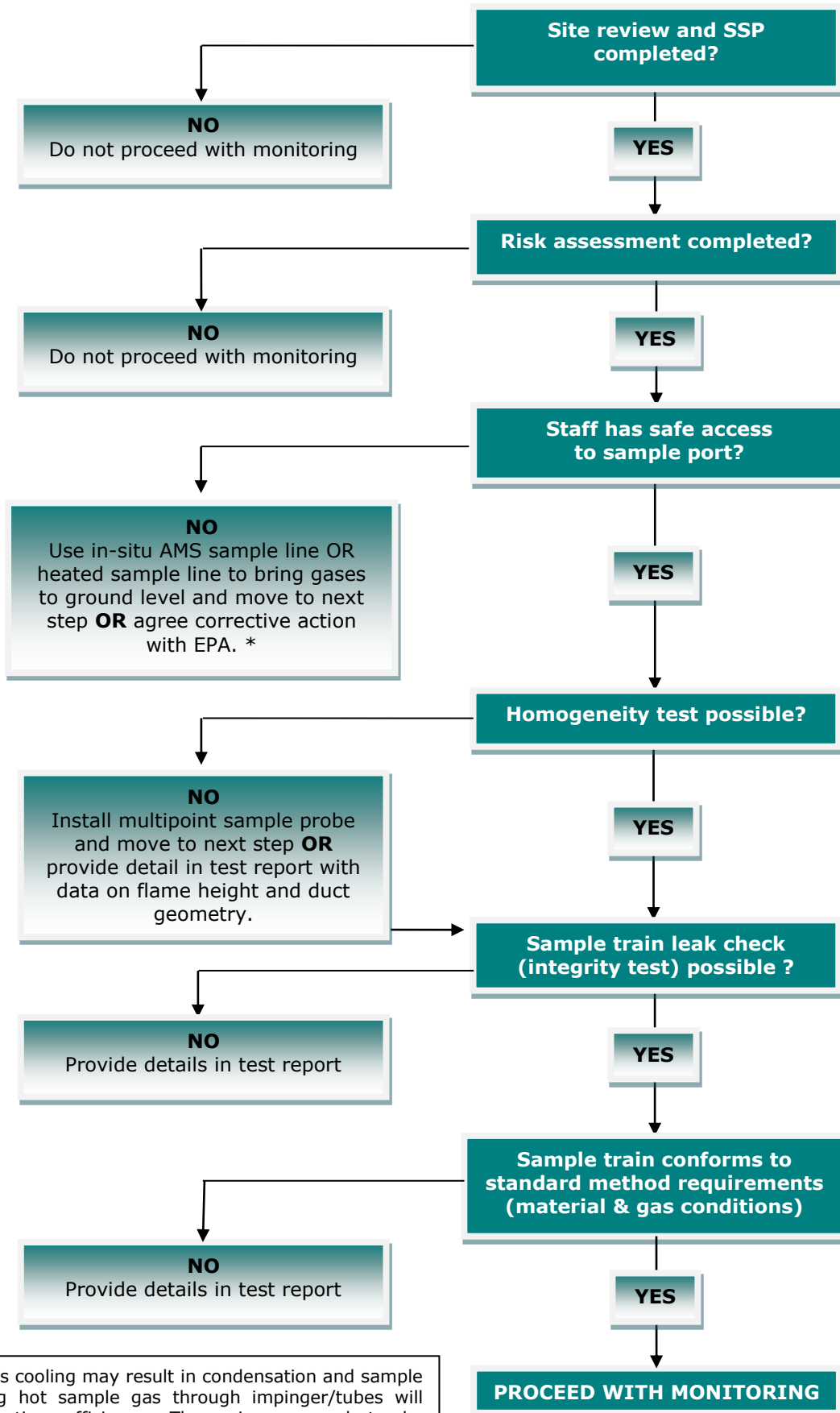
Refer to EPA guidance AG2ⁱⁱ for the general requirements on the content of monitoring reports. It is also recommended that the information listed in Appendices F be included with each monitoring report.

The following is a list of common omissions and errors that occur in flare and engine monitoring reports:

- Absence of basic information on site licence reference, emission point reference, time and date of sampling
- Absence of supporting information on the process which provides context to the emission results, (in particular the landfill gas management practices prior to day/hour of testing)
- No comment on the techniques employed that describe the measures taken to access the flare gas stream and sample it representatively (e.g. the use of in-situ AMS sampling line). Reports should state all components of the sampling/monitoring train (heated lines, heated filters, gas conditioning units, etc.)
- No AMS data provided for comparison with periodic emission results
- Reference to standard methods employed but no comment on degree of conformance (e.g. full) or any method modifications. What deviations from the standard arose due to access and safety issues at flare stack.
- Failure to state uncertainty of measurement and/or the basis for the uncertainty estimation.

3.12 Summary recommendations for monitoring at flares and engines

Figure 3.5 provides a flow chart with a series of yes/no questions that present the options which may be encountered during the course of the monitoring exercise.

Figure 3.5: Guide to flare monitoring using instrumental and manual sampling methods

* Sample gas cooling may result in condensation and sample loss, passing hot sample gas through impinger/tubes will reduce collection efficiency. These issues need to be addressed by way of temperature control and/or dilution devices and fully detailed in the monitoring report.

3.12.1 Recommendation for dealing with the absence of standard methods

- Select a standard method based on the hierarchy of standards defined in Section 2.13 of this report. CEN standards and some International Standards are available on the [NSAI web site](#). Refer also to the List of Preferred Methods in Appendix 1 of AG2
- Identify those aspects of the standard method which may render it unsuitable due to the high flare temperatures. These should be listed in the monitoring report, (substantial deviations from the standard method may render the data worthless)
- Identify those aspects of the standard method where a deviation is required due to the impaired access to flare gases. These should be list in the monitoring report
- Refer to Appendix D for the Source Testing Association schematic showing sample line arrangement for flare testing
- In ideal circumstances where it is necessary to modify a method it should be demonstrated to be equivalent to the relevant standard procedure by a process of validation, as specified in CEN/TS 14793:2004.

3.12.2 Recommendation on when to conduct monitoring

- When the volume and content of landfill gas varies with time, then information must be gathered on those factors that influence landfill gas so that the timing of the measurement can properly reflect the maximum emission (e.g. for use in compliance assessment)
- The monitoring report must detail the landfill gas conditions that prevailed during the monitoring event relative to historical data
- Do not undertake emissions testing on flares where operational/performance faults are known to exist. The proper functioning of abatement plant is an inherent requirement of waste licences and faulty plant should be repaired before testing commences
- Sampling probes should be installed immediately prior to the sampling campaign. Probes that are installed on a permanent basis (including those that are part of an AMS) can become corroded and may be unreliable.

3.12.3 Recommendation on monitoring issues

- Monitoring should take place at a location that is sufficiently downstream of the flame that the stream is homogenous and sufficiently upstream of the release point that the measurements are not influenced by wind movement, (refer to EPA guidance note AG1 for further detail on the selection of sampling location)
- Sampling probes should be constructed from a material that will withstand the thermal shock that results when flares switch on and off. Recommended material includes Inconel and stainless steel 316. Some metal probes can exude CO at flare temperature and cause erroneous test results
- Multi-point sampling probes (i.e. a tin whistle type design) can overcome concerns regarding the homogeneity of the waste stream. These probes need to be customised for the flare in question in order to achieve best results
- Flare gas temperatures will damage the PTFE core of a heated sampling line so a gas cooling device (section of suitable metal piping) should precede the PFTE. Optimise this arrangement by continuously monitoring the temperature in the cooling device and adjusting the sampling flow rate accordingly.

3.12.4 Recommendation on working safely in the vicinity of high temperatures

- Sampling staff should visit the site and conduct a risk assessment and review of facilities in advance of the monitoring event (not on the same day)
- A Safety Risk Assessment should be repeated on the day of monitoring and before any work commences
- All monitoring equipment should be set-up while the flare is switched off and all exposed surfaces have cooled sufficiently so that they do not present a risk to monitoring staff. Monitoring set-up is a key component of a successful monitoring event and should be carefully planned and agreed by landfill operator and the testing contractor

- Stack testing staff should never access sampling port during flare operation or cool down. A lock-out system must be put in place to ensure that the flare remains off and cooled down prior to staff accessing the sampling ports
- Access for the purpose of setting up sampling probes and equipment may employ a permanent platform, a suitable temporary platform (scaff-tagged) or a MEWP
- Instrumental techniques - Heated lines and coolers should be used to deliver stack gases from sampling plane to ground based analysers
- It may be possible to modify manual sampling techniques for the measurement of certain gaseous species (e.g. non-isokinetic sampling). Stack gas can be drawn to ground level via a heated line, then employ sample gas cooling or dilution (as appropriate) before entrainment in impingers or on sorbent tubes.
- Manual sampling techniques (i.e. for particulate/aerosol using isokinetic extraction) will rarely be justified. Where particulate emissions are suspected then alternative means of verification may include a technical examination (e.g. inlet filters nozzle condition) or indicate methods for particulate monitoring using a ringelmann chart. The monitoring of dioxins has little validity because the sample gas will undergo cooling when extracted from the stack and this can be a source of dioxin formation
- The use of a FTIR is a valuable option for the monitoring of gaseous species that are otherwise normally measured using extractive techniques.

4. RECOMMENDED FLARE AND ENGINE OPERATION AND MAINTENANCE PRACTICES

This section will review key management factors for:

- Flares
- Engines
- Standby capacity
- Unit sizing, commissioning and decommissioning
- Landfill gas philosophy
- Gas collection infrastructure impacts on flare and engine operation.

4.1 Flare operational & maintenance practices

Current best practice in Ireland assumes emissions compliance if the flare is operating within the manufacturers guidelines. Continuous and non-continuous emissions monitoring is carried out thereafter to validate this assumption.

In relation to landfill gas flares, management of the following parameters are critical for emissions control:

- Extraction flow rate
- CH₄ concentration
- O₂ concentration
- Stack temperature
- Routine maintenance.

4.1.1 Impacts of extraction flow rate on flare operation

Flares have a design flow range over which the emission limits will be achieved. The upper flow limit is typically defined assuming a CH₄ concentration of 50 % v/v. The lower flow rate limit is typically defined in terms of turndown ratio. If the flare had an upper limit rated capacity of 1,000 m³/hour and a turn down ratio of 10:1 the lower limit flow rate of the flare would be 100 m³/hour.

Management of extraction flow rate should attempt to ensure continuous flare operation within respective flare defined limits. Where this is not possible a **SSRA** needs to be carried out in accordance with Section 2.4 of this guidance note.

4.1.2 Impacts of CH₄ concentration on flare operation

Typically the upper extraction flow rate for most flares is defined for landfill gas having a CH₄ concentration of 50 % v/v. If for example, a CH₄ concentration of 55% v/v occurs it may reduce the extraction flow rate by up to 70% of the upper design flow rate as the flare may not be able to maintain the appropriate air fuel mix within temperature limits.

Where low CH₄ quality is the limiting factor operators may restrict flows (decrease extraction) to increase the methane concentration. If this occurs it is possible that landfill gas production exceeds extraction and fugitive emissions from the facility may increase.

Where low or high CH₄ landfill gas concentrations compromise flare operation, a **SSRA** needs to be carried out in accordance with Section 2.4 of this guidance note.

4.1.3 Impacts of O₂ concentration on flare operation

Typically flares in Ireland are programmed to shut down for O₂ concentrations greater than 6 % v/v to mitigate the risk of explosion. Proactive management of the landfill gas collection system is therefore required to minimise oxygen within the incoming (extracted) gas.

If oxygen ingress is excessive in order to manage fugitive emissions and flare operation is compromised, a **SSRA** needs to be carried out in accordance with Section 2.4 of this guidance note.

4.1.4 Impacts of temperature on flare operation

Flares are typically programmed to manage stack temperatures between 1,000°C and 1,200°C. The lower temperature limit is typically defined by licence conditions.

If enclosed flares are operated at temperatures below 1,000°C, stack emissions of pollutants might increase. Most notably lower temperatures will increase the risk of emissions associated with odours such as mercaptans from the stack outlet.

If flares are operated below temperatures of 1,000°C, a **SSRA** needs to be carried out in accordance with Section 2.4 of this guidance note.

This may occur e.g. in a situation where continuous extraction is only possible at a lower stack temperature because CH₄ concentration is limiting.

Flares should not be operated at temperatures greater than 1,200°C and it is common for the flare combustion process controls to prevent such. If stack temperatures exceed 1,200°C then concentrations of NO_x increase.

4.1.5 Routine flare maintenance

Waste licences require flares to be maintained. Typical conditions are presented below:

"All treatment/abatement and emission control equipment shall be calibrated and maintained, in accordance with the instructions issued by the manufacturer/supplier or installer. Written records of the calibrations and maintenance shall be made and kept by the licensee (or similar).

Monitoring and analysis equipment shall be operated and maintained as necessary so that monitoring accurately reflects the emission/discharge (or ambient conditions where that is the monitoring objective)".

These conditions require that landfill gas flares, engines and associated infrastructure (such as flow, O₂, CH₄, CO, NO_x and temperature sensors) are maintained in accordance with the manufacturer/supplier or installer recommendations. A generic flare routine maintenance schedule is presented in Appendix E. This outlines inspections/services to be undertaken on a flare by the licensee daily, weekly, monthly, quarterly, yearly and every three years.

The licensee should also have spare equipment onsite or readily available in the case of typical breakdowns which will impact emissions and these include:

- Thermocouples
- UV sensor
- Ignition transformer
- Louvre actuator
- Analyser cells
- Analyser filters.



In general if flares are operated and maintained in accordance with the manufacturers recommendations, emissions will be compliant with licence conditions. It is recommended that records of all maintenance activities be retained on site by the licensee for the appointed monitoring contractor and the EPA to review.

4.1.6 Summary of flare performance parameters

Table 4.1 provides a summary of the typical parameters that impact the performance of flares which in turn can impact emissions which have been discussed above. When carrying out an emission monitoring assessment, the contractor should make reference to this data to assess if the unit in question is operating within individual parameter ranges.

Table 4.1: Typical Flare Emissions Related Performance Parameters

Performance Related Parameters	Parameter Range	Typical Monitoring on Irish Sites
Temperature	1000°C to 1200°C	Continuous
Burn time	Continuous	Continuous
Retention time ^{Note 1}	0.3 s	Periodic calculation
O₂ (inlet)		Continuous
ATEX EX Rating 2 ^{Note 2}	<6% v/v	
ATEX EX Rating 1 ^{Note 2}	<10%	
CO₂ (inlet)	(not required for flare management)	Continuous
CH₄ (inlet)		Continuous
High calorific flare	>27 to 30 %	
Low calorific flare	>10%	
Open Flare	>15%	
Flow rate (inlet)	Subject to flare size	Continuous
Turn down ratio ^{Note 3}		
High calorific flares	5:1 to 10:1	n/a
Low calorific flares	< 5:1	n/a
Open flares	>10:1	n/a
Site Specific Parameters ^{Note 4}		
Carbon monoxide	50 mg/m ³	Continuous
Nitrogen oxides	150 mg/m ³	Periodic
Hydrogen chloride	50 mg/m ³ @ mass flow > 0.3 kg/h	Periodic
Hydrogen fluoride	5 mg/m ³ @ mass flow > 0.05 kg/h	Periodic
Total organic carbon	10 mg/m ³	Periodic

Note 1: Site assessment of retention time (residence time) requires definition of incoming flow rates from landfill gas and air through the dampers. Whilst it is possible to measure flow rates of incoming landfill gas, flow rate of air through dampers is typically calculated. Few licences require continuous assessment of residence time

Note 2: Oxygen concentration is linked to the ATEX EX rating of the flare and its component parts. ATEX EX Zone 2 rating allows short term oxygen concentration above 6% v/v. Zone 1 rating allows long term operation at O₂ concentrations above 6% v/v

Note 3: Flares have a design flow range over which the emission limits will be valid. The upper limit is typically defined assuming a methane concentration of 50 % v/v

Note 4: Subject to site specific risk assessments.

4.2 Engine operational & maintenance practices

The key operational parameters for the engine management system are:

- Extraction flow rate
- CH₄ concentration
- O₂ concentration
- Cylinder temperature
- Engine management settings
- Routine maintenance.

4.2.1 Impacts of flow rate on engine operation

Engines require approximately 600 to 675 m³/hour of landfill gas at 50 %v/v CH₄ to produce 1 MW of electricity^{xxv}. The relationship between power generation load and landfill gas extraction flow rate is not linear. As the power generation load reduces, the demand for landfill gas reduces at a greater rate because the CH₄ concentration increases with reduced extraction. Typically the extraction flow rate for a 1 MW rated unit may vary from 675 m³/hour to 300 m³/hour as a consequence of a reduced load and/or available gas quality.

Engines are typically programmed to maximise power output. Engines run at continuous speed. If gas quality within the incoming landfill gas changes, the engine management system will change the:

- Incoming air to maintain an air-fuel ratio, and/or
- The blower flow rate (gas extraction) to maintain a defined inlet pressure to the engine.

Air fuel ratio changes impact engine emissions, while inlet pressure changes impact landfill gas extraction flow rate and thus facility fugitive emissions.

Typically engines will shut down if they are operating at less than 50 % of their load. Particularly where engine management systems are not programmed to control exhaust ELVs, maintaining continuous steady state flows of uniform gas quality mitigates the risk of emissions exceeding exhaust ELVs and other facility fugitive emissions. This requires a structured field based extraction philosophy and operations policy to manage gas quality and flow to the engines.



If extraction is not continuous and/or at a steady extraction flow rate of uniform gas quality a **SSRA** may need to be carried out in accordance with Section 2.4 of this guidance note.

4.2.2 Impacts of methane on engine operation

Engine controllers adjust the air to fuel ratio automatically as the methane content of the supply gas changes, within an operating range of 45 ± 15 per cent CH₄ v/v.^{xxvi}

The engine's ability to manage fuel variation is dependent upon its design age. Early utilisation plants (c. 1980) required 50 %v/v CH₄. Below this, the engines were unable to maintain load and were automatically shut down. These engines whilst having good combustion efficiencies also tended to have higher NO_x emissions.

Engines manufactured in the 1990s used engine management systems to facilitate lean burn systems and the CH₄ range was extended between 42 %v/v and 55 %v/v. However to maintain TA Luft emission standards some manufacturers recommend that the load be reduced by 5 % for every 1 % reduction in methane below 50 % v/v. Whilst this feature is automatically configured from the factory, it can be switched off by the operator.

If methane concentration varies and has the potential to impact emissions and if engine management systems are not programmed to automatically adjust for same, a **SSRA** needs to be carried out in accordance with Section 2.4 of this guidance note.

4.2.3 Impacts of oxygen concentration on engine operation

O₂ is required for the combustion process. Landfill gas engines are more sensitive to O₂ ingress from the gas collection system than flares such that engines may be programmed to shut down if O₂ exceeds 3 to 4 % v/v (limits up to 6 % v/v can be accommodated). Proactive management of the landfill gas collection system is therefore required to minimise O₂ within the incoming (extracted) gas. Typically when methane concentration reduces, the air intake flow rate (oxygen) to the engine increases and combustion temperatures rise.

If incoming oxygen or oxygen concentration within the combustion process varies and has the potential to impact emissions and if engine management systems are not programmed to automatically adjust for same, a **SSRA** needs to be carried out in accordance with Section 2.4 of this guidance note.

4.2.4 Impacts of temperature management on engine operation

Each manufacturer has a different philosophy in managing engine temperature control. For example, the mean cylinder temperature may be controlled by managing the fuel to air ratio or by modulating the fuel pressure using turbochargers. The engine management system will typically try to maintain a mean cylinder temperature of 450°C and the engine will shut down if this temperature is not maintained.

As engine management systems typically work on a mean temperature some cylinders will have a higher temperature than others. Low temperature cylinders will tend to produce higher CO emissions and high temperature cylinders will increase the emissions of NO_x.

Where individual cylinder temperatures have the potential to impact emissions, a **SSRA** needs to be carried out in accordance with Section 2.4 of this guidance note.

4.2.5 Engine management settings

Engine management control systems typically have a primary objective to manage power output. Secondary settings within the engine management system may also be available to manage the combustion process to:

- Prevent CO emissions exceeding ELVs
- Prevent NO_x emissions exceeding ELVs.

Where continuous emissions monitoring is available, the monitoring contractor needs to assess whether or not the continuous monitoring information is used to control the combustion process to maintain ELVs within licence limits.

Where engine management systems are not programmed to control emissions within ELVs, a **SSRA** needs to be carried out in accordance with Section 2.4 of this guidance note.

4.2.6 Engine routine maintenance

As outlined earlier, waste licence conditions require that landfill gas engines and associated infrastructure (such as flow, O₂, CH₄, CO, NO_x and temperature sensors) are maintained in accordance with the manufacturer/supplier or installer recommendations.

Following a regular maintenance procedure, engines will have been tuned to manage emissions for a specified gas flow rate and quality. Calibration requirements for sensors, associated wear and tear, and build-up of deposits within the combustion system, all impact upon the emissions and ELVs will change or drift. The engine management system will typically adjust control parameters to maintain power output (unless emissions are the primary control objective) and in doing so may increase CO emissions or NO_x.

emissions. Site specific routine maintenance may therefore be required to mitigate the risk of emissions exceeding licensed limits.

Where maintenance is the primary control mechanism to maintain emissions within ELVs, a **SSRA** needs to be carried out in accordance with Section 2.4 of this guidance note with evidence that the maintenance regime and the control of incoming gas flow rate and quality are sufficient to maintain emissions within site specific ELVs for respective maintenance intervals.

Items that may have a significant impact on emissions drift are:

- Valve clearances
- Spark plug condition
- Engine air filters
- Crankcase breather condition
- Oil consumption
- Ignition timing
- Intercooler condition
- Deposits within the combustion chamber and or cylinder head between maintenance intervals.

Maintenance regimes for engines are complex and it is not practicable to review them in detail. However, if during a monitoring assessment, the monitoring contractor identifies that the upper limit of CO or NO_x drift is greater than licenced conditions permit, a recommendation should be made to the operator by the monitoring contractor to review the operational and/or maintenance procedures/frequency for that unit. As per each waste licence, it is a requirement that records of all maintenance activities are retained on site by the licensee for review by the EPA. These should also be reviewed by the appointed monitoring contractor.

4.2.7 Summary of engine performance parameters

Table 4.2 provides a summary of the typical parameters that impact the performance of engines which have been discussed earlier. When carrying out an emission monitoring assessment, the contractor should make reference to this data to assess if the unit in question is operating within individual parameter ranges.

Table 4.2: Typical Engine emissions related performance parameters

Performance Related Parameters	Parameter Range	Typical Monitoring on Irish Sites
Temperature	450°C	Continuous
Run time	Continuous	Continuous
O₂ (inlet)	< 6% v/v	Continuous
CO₂ (inlet)	(not required for engine management)	Continuous
CH₄ (inlet)		
Commissioned in 1980's	50% to 55% v/v	Continuous
Commissioned in 1990's	42% to 55% v/v	Continuous
Flow Rate		Continuous
Site Specific Parameters ^{Note 1}		
CO	50 mg/m ³	Continuous
NO _x	500	Periodic
Particulates	130	Periodic
Hydrogen chloride	50 mg/m ³ @ mass flow > 0.3 kg/h	Periodic
Hydrogen fluoride	5 mg/m ³ @ mass flow > 0.05 kg/h	Periodic
TA Luft Organic Class 1	100 mg/m ³ @ mass flow > 2 kg/h	Periodic
TA Luft Organic Class II	150 mg/m ³ @ mass flow > 3 kg/h	Periodic
TA Luft Organic Class III	20 mg/m ³ @ mass flow > 0.1 kg/h	Periodic
Total non-volatile organic carbon	75 mg/m ³	Periodic
Total volatile organic carbon	1,000 mg/m ³	Periodic

Note 1: Subject to site specific risk assessments.

4.3 Flare and engine destruction and removal efficiency

Guidance^x advises that landfill gas may contain up to 500 trace components. Site based destruction efficiency monitoring of trace components is therefore not practicable and periodic assessments of site specific parameters are required.

Destruction and removal efficiencies of VOCs in flares and engines are typically greater than 98 % when units are operated in accordance with manufacturer's recommendations.

Management of emissions compliance in engines is however more complex particularly when Irish licensed sites do not typically link continuous emissions monitoring to engine management. Consider a case where the management system uses average cylinder temperature as the primary parameter for combustion control. If between maintenance intervals wear and tear or deposit build-up varies between cylinders which will in turn impact on respective cylinder temperatures there may be a negative impact on say NO_x or CO.

Consider another case where the ignition timing is set to facilitate low exhaust nitrogen oxide emissions. This may reduce engine combustion efficiency and carbon dioxide and volatile emissions may increase^{xxvii}.

In general, increasing emissions of CO are indicative of reducing combustion efficiencies. CO emissions will tend to increase (drift) between maintenance intervals as will NO_x emissions when control of these parameters is not the primary engine management objective.

4.3.1 Assessment of flare and engine destruction and removal efficiency

To assess engine and flare efficiency during a monitoring assessment CO emission trends should be reviewed. If there is an increase in CO or NO_x emissions this may indicate the need for maintenance and or operational adjustments.

In addition the inspection of the respective units need to review operating criteria, maintenance records and combustion management records/settings to assess whether or not units are being maintained and operated to facilitate emission control within licenced conditions.

Where continuous monitoring is not available or where engine management systems are not programmed to control emissions within ELVs, a SSRA needs to be carried out in accordance with Section 2.4 of this guidance note to demonstrate that maintenance intervals and methodologies for respective units are sufficient to ensure drift remains within licence ELVs.

4.4 Standby capacity

Standby capacity needs to be provided for routine maintenance and unforeseen conditions affecting the operation of landfill gas flares and engines.

Engines require significant maintenance which requires down time at pre-defined hourly intervals. Maintenance intervals may also be influenced significantly by gas quality and allowable ELVs. Routine maintenance is structured and standby capacity (be it provided by engines or flares) can be easily defined and arranged for site specific conditions.



Emergency standby capacity will vary subject to size of site and prevailing conditions. It is recommended that a **SSRA** is carried out in accordance with Section 2.4 of this guidance note, to define the required emergency standby capacity for each site.

Emissions testing of standby units are required unless otherwise agreed by the EPA. It is recommended that consideration be given to UK Environmental EA guidance which states if standby flare units are operational for less than 876 hours, in any given year, emissions monitoring is not required.

4.5 Unit sizing, commissioning and de-commissioning

Gas prediction curves provide the overall gas prediction estimate and are prepared by operators as part of the annual environmental report (AER). The curves typically have steep rises, a period of steady state production and rapid fall offs.

Lead times for supply of both flares and engines may be significant. Therefore calibrated gas prediction curves are required for accurate planning in order to avoid emission related problems as a consequence of installed equipment not being fit for purpose (e.g. undersized) and/or replacements being required at short notice.

Thereafter specification of equipment constraints particularly in relation to flare turn down ratios should be managed to maximise cost effective flare longevity. Flares should be specified in such a way as to allow modifications at minimal cost e.g. by retaining blower assemblies and replacing burner and stacks to allow lower turn down ratios.

4.6 Landfill gas management

This section is provided to give background information on management factors impacting flare, engine and facility emissions.

4.6.1 [Extraction philosophy](#)

Licence conditions typically require:

- Flaring or utilisation of all landfill gas
- Emissions compliance in relation to defined parameters.

Landfill operators need to define an extraction philosophy and implement structured operational practices to extract landfill gas as it is being produced and to manage gas quality and flow to engines and/or flares. To achieve this, the following information/systems need to be in place:

- Accurate (calibrated) gas prediction curve
- Engine and flare commissioning and decommission program
- Extraction criteria for balancing in relation to one or more of the following:
 - O₂
 - CH₄
 - N₂
 - Flow rate
- Balancing protocol
- Auditing protocol.

4.6.2 Impact of site development on emissions

Flares and engines will most likely have stack emission related problems as a consequence of variations in landfill gas flow and/or quality. This typically occurs when:

- Landfill gas is not available in the quality and or quantity for unit requirements. This may occur:
 - At the beginning of a landfill's life
 - At the end of its life
 - As a consequence of biodegradable waste diversion targets reducing organic content
 - If landfill gas production flow rates are outside the units specification for continuous operation
- Excessive oxygen ingress occurs or insufficient methane is captured. This may occur due to inadequate:
 - Site/system design
 - Facility operations/management
 - Facility gas collection system maintenance
 - Maintenance of engines or flares.

For ease of reading it is important to understand the following terms:

- Gas collection system **capture efficiency** describes the landfill gas oxidised in engines, flares or biological filters as a percentage of the total landfill gas produced
- **Fugitive emissions** from a facility refer to landfill gas not oxidised in engines, flares or biological filters.

An emissions assessment of engines and flares needs to determine if gas extraction flow rates are managed solely to facilitate ELVs compliance of the flares and engines, this may result in an increase in facility fugitive emissions (typically from the surface sides or base of a waste body).

If landfill gas flow to the units is being restricted either by reducing flows to increase methane or reducing oxygen concentration or by cutting back on hours of extraction, fugitive emissions may be released from the facility. If any one of these impacts occur, a **SSRA** needs to be carried out in accordance with Section 2.4 of this guidance note.

Historically, the assessment of fugitive emissions was carried out using flux boxes. More recently the EPA has approved the use of VOC surveys^{vi}. A useful supplement to these surveys and one that can be carried out on site during an emissions assessment to assess capture efficiency by presenting:

- **Total extraction flow rate in m³/hour** of the flare and/or engine (available from emissions survey) as a percentage of the **total landfill gas production in m³/hr** for a defined period (available from the AER for the previous year).

The capture efficiency will vary significantly depending on basal liner type, extent and type of final cap, infrastructure design and infrastructure management. If capture efficiencies are greater than 100% then the landfill gas prediction curves may be inaccurate and will need to be re-evaluated by the operator. Similarly if capture efficiencies are low (e.g. less than 85% for a fully capped site) then the conditions limiting such, need to be defined.

Whilst this methodology is not designed to replace VOC surveys^{vi}, it facilitates a definition of potential emissions related issues in terms of a flow rate that can easily be related to flare and or engine extraction capacity.

APPENDIX A TRACE COMPONENTS IN LANDFILL GAS**Table 1: Priority Trace Components in Landfill Gas**

Trace component	CAS number	Potential impact	Category
1,1-dichloroethane	75-34-3	Health	Halocarbon
1,2-dichloroethane	107-06-2	Health	Halocarbon
1,1-dichloroethene	75-35-4	Health	Halocarbon
1,2-dichloroethene	540-59-0	Health	Halocarbon
1,3-butadiene	106-99-0	Health	Aliphatic hydrocarbon
1-butanethiol	109-79-5	Odour	Organosulphur
1-pentene	109-67-1	Odour	Aliphatic hydrocarbon
1-propanethiol	107-03-9	Odour	Organosulphur
2-butoxyethanol	111-76-2	Health	Alcohol
Arsenic (as As)	7440-38-2	Health	Inorganic
Benzene	71-43-2	Health	Aromatic hydrocarbon
Butyric acid	107-92-6	Odour	Carboxylic acid
Carbon disulphide	75-15-0	Odour and health	Organosulphur
Chloroethane	75-00-3	Health	Halocarbon
Chloroethene (vinyl chloride)	75-01-4	Health	Halocarbon
Dimethyl disulphide	624-92-0	Odour	Organosulphur
Dimethyl sulphide	75-18-3	Odour	Organosulphur
Ethanal (acetaldehyde)	75-07-0	Odour	Aldehyde
Ethanethiol	75-08-1	Odour	Organosulphur
Ethyl butyrate	105-54-4	Odour	Ester
Furan (1,4-epoxy-1,3-butadiene)	110-00-9	Health	Ether
Hydrogen sulphide	7783-06-4	Health and odour	Inorganic
Methanal (formaldehyde)	50-00-0	Health	Aldehyde
Methanethiol	74-93-1	Odour	Organosulphur
Styrene	100-42-5	Health	Aromatic hydrocarbon
Tetrachloromethane	56-23-5	Health	Halocarbon
Toluene	108-88-3	Health	Aromatic hydrocarbon
Trichloroethene	79-01-6	Health	Halocarbon
Mercury (as Hg)	7439-97-6	Health	Inorganic
PCDDs and PCDFs	N/A	Health	Chlorinated aromatic
Carbon monoxide	630-08-0	Health	Inorganic

CAS = Chemical Abstracts System

Source: Environment Agency 2010, *Guidance for Monitoring Trace Components in Landfill Gas*^x

APPENDIX B FURTHER DETAILS ON-SITE SPECIFIC RISK ASSESSMENT

Site specific risk assessments (SSRA) are an important tool when a site cannot comply with the requirements of its waste licence and due to this, has a potential impact the local environment. With regards to landfill gas infrastructure operational management, maintenance and monitoring, if a site cannot comply with the requirements of its licence, a SSRA can be undertaken. This SSRA will determine if alternative approaches/practices would be better for managing landfill gas in order to balance potential environmental conflicts between oxidised emissions and fugitive emissions from the landfill.

A risk assessment is the formal process of identifying, assessing and evaluating the risks to health and the environment that may be posed by the condition of a site. If contamination is present, a risk assessment helps decide whether it is a problem or not.

The risk assessment process is an iterative approach where initial site data enables a model of the site to be created. With regards to landfill gas, this assessment requires an in depth understanding of the nature of waste accepted/to be accepted onsite, the design of landfill gas infrastructure proposed or onsite, landfill gas infrastructure operation, landfill gas quantification and quality, and the environmental setting in which the site is located. This conceptual site model is refined as further data is obtained, for example, through desk studies, walkover surveys and intrusive investigations.

The risk assessment will be undertaken in three stages:

- The first stage of a risk assessment is to identify and assess the hazards present, i.e. substances with the potential to cause harm to the receptors.
- The second stage in a risk assessment is to consider how much, how often and for how long the receptor is exposed to the hazard (exposure assessment), as well as the effect on the receptor of the exposure (consequence assessment). This will enable a concentration to be estimated which can then be related back to the hazard assessment.
- The final stage in a risk assessment is to evaluate the above stages with risk estimation, in which the consequences and probability of the risk is considered, with risk evaluation in which the significance or seriousness of the risk is considered.

The risk assessment can also be undertaken in a tiered approach where the level of effort put into assessing each risk is proportionate to its magnitude and its complexity:

Tier 1: Hazard identification and risk screening.

Tier 2: Simple quantitative risk assessment - these assessments should be undertaken when the previous risk screening is insufficient to make an informed decision on the risks posed by the site.

Tier 3: Complex quantitative risk assessment - Complex risk assessments should be carried out when the site setting is sufficiently sensitive to warrant detailed assessment and a high level of confidence is necessary to ensure compliance with legislation

Further information on-site specific risk assessments can be found at:

- Environment Agency *Guidance on the Management of Landfill Gas*, 2004^{xxv}
- Environment Agency Horizontal Guidance Note H1 - Environmental risk assessment for permits, 2010^{xxviii}.

APPENDIX C DATA STANDARDISATION CALCULATIONS

A typical landfill licence condition will require that limits for emissions to atmosphere shall not be achieved by introduction of dilution air and shall be based on gas volumes under standard reference conditions.

In the case of flares those conditions are:

Temperature 273 K, Pressure 101.3 kPa, dry gas, 3% oxygen

In the case of landfill gas combustion plant the reference conditions are:

Temperature 273 K, Pressure 101.3 kPa, dry gas, 5% oxygen

Some licences may vary from the conditions stated here.

Units of measurement

The following units are used in emission monitoring.

Units	Description
Mass concentration	The mass of pollutant per unit volume of waste gas emitted (e.g. mg/Nm ³)
Volume concentration	The volume of pollutant per unit volume of waste gas emitted (e.g. ppm, ppb)
Volumetric flow rate	The volume of waste gas emitted per unit time (e.g. Nm ³ /hr)
Mass flow rate	The mass of pollutant emitted per unit time (e.g. kg/hr)
Mass flow threshold	A mass flow rate, above which, a mass concentration limit applies (e.g. 5 mg/m ³ at a mass flow of > 0.05 kg/hr).

Normal temperature and pressure

Normal Temperature and Pressure (NTP) are defined as 273.15 Kelvin (K) and 101.325 kiloPascal (kPa).

To convert the **concentration** as measured at a temperature of T K to the concentration at 273.15 K, multiply by F_t where:

$$F_t = T/273.15$$

To convert the **concentration** as measured at a pressure of P kPa to the concentration at 101.325 kPa, multiply by F_p where:

$$F_p = 101.325/P$$

Moisture and oxygen corrections

To convert a **concentration** from wet gas to dry gas the following is used:

$$\text{Dry gas concentration} = \text{Wet gas concentration} \times \{100 / (100 - H_2O\%)\}$$

To convert a **concentration** 'as measured' to a concentration at reference oxygen level (as specified in each waste licence 3 % for flares and 5 % for engines), multiply the concentration by F_o , the correction factor for oxygen, given by:

$$F_o = \{20.9 - O_2\% \text{ reference} \} / \{20.9 - O_2\% \text{ measured} \}$$

Note that when using this equation the measured oxygen value should be expressed on a dry gas basis, unless otherwise agreed with the EPA. These equations should only be used to convert mass concentration. Use the reciprocal equations when volume flow data needs to be corrected for moisture and reference oxygen.

Mass emission flow rate

The mass emissions rate is the weight of pollutant emitted per unit time and it can be calculated as follows:

$$\text{Mass emission rate} = \text{mass concentration} \times \text{volumetric flow rate}$$

When calculating the mass emission rate, the concentration and volume flow terms must be in the same units of temperature, pressure and reference conditions.

APPENDIX D SOURCE TESTING ASSOCIATION (STA) TECHNICAL GUIDANCE NOTE (TGN 024)



Technical Guidance Note TGN 024

Monitoring of Landfill Gas Flares and Gas Engines

Issue Date April 2006, supersedes none

Source Testing Association

Tel +44(0) 1462 457535 Web Site www.s-t-a.org
Fax +44(0) 1462 457157 E-mail technical@s-t-a.org

Background

The Environment Agency Guidance on Landfill gas flare monitoring outlines a monitoring strategy that requires pre-installation of an extraction system to take a representative sample from above the flame within the enclosed flare stack. It presumes (unless demonstrated otherwise) that there may be non-uniform distribution of gas concentrations across the sampling plane and that a multipoint sample probe/sampling would normally be required.

Sampling System

The installed system, see figure 1, comprises a ceramic multi-hole probe which is fitted across the stack with a coil condenser (heat exchanger) fitted to a temperature-controlled heated sample line. The heated line has an integral calibration line and a thermocouple to monitor the temperature of the sample gas entering the heated line.

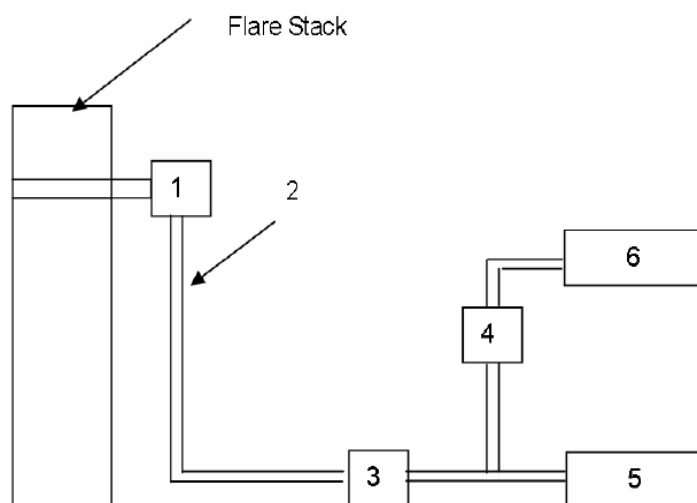


Figure 1 Gas sample system

Legend

1. Sample probe and cooler
2. Heated sample line with integral calibration line
3. Heated purge valve system
4. Gas conditioning system
5. Heated FID TOC analyser
6. Analyser(s) for monitoring CO, NO_x and optional SO₂

Flare operation

Flares must meet operational standards as well as emission standards. Part of risk minimisation is to avoid monitoring flares that fail to meet operational standards. It is the responsibility of the operator to ensure that operational standards are met. In addition, the effectiveness of permanently installed sampling equipment is also the operator's responsibility.

For the duration of emissions testing, monitoring teams must ensure that the flare is operating under acceptable conditions.

Flares can be operating outside acceptable standards; if for example:

- The flame extends beyond the shroud at any time (it should be below the sampling ports) – elevated or un-enclosed flares must not be monitored.
- On noting the operating temperature, it is outside the design range **by more than 100° C**. Normal operation for most designs is 1000° C.
- The temperature fluctuates **by more than 100° C over a 5 minute** period (indicative of problems in the gas field so may be noted as a factor in representativity of data).
- The thermocouple temperature is significantly different from that shown on the flare control temperature instrument.
- There are missing or broken louvers on the air control (this will affect estimation of flow).
- The orifice plate or similar flow gauge is not operational.
- There is a strong smell of landfill gas in the compound.
- A recent value for gas composition is not available.

Monitoring

The main measurements that are to be carried out are;

- Nitrogen Oxides (NO_x) to BS EN 14792:2005
- Carbon Monoxide (CO) to BS EN 15058:2006
- Total Organic Compounds (TOC) to BS EN 13526

Optional:

- Sulphur Dioxide (SO₂) to BS 6069 part 4.4 (ISO7935)

Preparation at site

The test team is to verify, before sampling, that the heated line system is functioning correctly by ensuring that:

- the heated line has no hot or cold spots within its length;
- the temperature of the sample gas (downstream of the cooler and before the heated line) is above 180°C;
- after the analyser(s) system is connected, there are no leaks by following the procedure in BS EN 14792 paragraph 8.4.2.3;
- the analysers must be calibrated by introduction of span and zero gases directly into the analyser and then via the sample system. The difference between the two readings must be less than **two per cent** of the estimated measured concentration as stated in the relevant standards.

Measurements

The sampling period for the measurement must be determined and should cover at least one cycle of flare operation. The analyser data recording system must be able to record **one minute** averages.

On completion of the sampling period you must carry out a check of the sample system as stated in the relevant standards.

APPENDIX E EXAMPLE FLARE MAINTNANCE CHECKLIST (TO BE COMPLETED BY LICENSEE)

Flare Maintenance Checklist	Site Location	
	Date	
	Inspector	
	Units	Comment
1) Daily Inspection		
CH ₄	% Vol.	
CO ₂	% Vol.	
O ₂	% Vol.	
CO	PPM	
Record booster operational hours	Hrs	
Flow rate	M ³ /hr	
Suction pressure	Mbar	
Flare Temperature	C°	
2) Weekly Inspection		
Is pilot line free of condensate?		
Is emissions sample line clear?		
Is there adequate flow through the analysers?		
Is the UV sensor free of dirt and aimed correctly?		
Check flare temp and louvre operation		
Check pots for condensate build up		
Check for any obvious defects		
Condensate Pump (Hour Clock / Cycle Counter)		
Compressor - pressure & condensate check	Bar	
3) Monthly Inspection (to include items above)		
Calibrate Rosemount analyser or Equivalent (flow, O ₂ , CH ₄ , CO, NO _x , temperature sensors, etc.)		
Are there any gas leaks in or around the skid?		
Is the ignition probe correctly positioned?		
Are the condensate collection tanks empty?		
Pressure drops across the flame traps	mbar	
Clean the pilot flame trap		
Check for any obvious defects throughout		
Abnormal Noise		
Oil / Grease stains or leaks		
4) Quarterly Inspection (to include items above)		
Blow down compressor		
Check pressure relief valve		
Check Air Dryer operation & condition		
Clean flame arresters		
Examine burner tips for deterioration		
Calibrate Rosemount analyser or Equivalent (flow, O ₂ , CH ₄ , CO, NO _x , temperature sensors, etc.)		
Check safety chain		
Change oil in booster		
Check belt tension		
Clean pilot solenoid filter		
Clean Demister Filter		
Check for excess vibration/noise in skid		
Check temp. in skid and extractor fan operation		
Any obvious defects		
Check integrity of wiring/connections		
Grease Motor bearings & Shaft Seals		
5) Annual Inspection (to include items above)		
Change drive belts		
6) Every Three years (to include items above)		
Motor / booster bearings & shaft seals		
Inspect anti vibration mounts		

APPENDIX F: OPERATIONAL MANAGEMENT AND MAINTENANCE CHECKLIST (TO BE COMPLETED BY MONITORING CONTRACTOR AND LICENSEE)

Site Location:				
Date:				
Monitoring Contractor:				
Licensee:				
Operational Parameters	Units	On day of Inspection	Previous year	Comments
Landfill Gas Management				
Is extraction continuous 24/7	Y/N			
Continuous burn (run time)	hours			
Hours not operational	hours			
How many odour related complaints were received in the preceding 12 months	Number			
Operational Practices				
Temperature				
Average temperature flame	°C			
Pressure				
Barometric pressure	mbar			
Pressure u/s of knockout pot	mbarg			
Inlet Parameters				
Average CH ₄	v/v %			
Average O ₂	v/v %			
Average CO ₂	v/v %			
Outlet Parameters				
Average CO	v/v %			
Average NO _x	v/v %			
Other - provide details e.g. evidence of increasing CO levels				
Maintenance Practices				
Is flare/engine serviced routinely?	Y/N			
Servicing interval	months			
Previous Service Date	Date			
Are monitoring sensors serviced/calibrated routinely?				
Servicing interval	months			
Previous Service Date	Date			
CH ₄	Y/N			
O ₂	Y/N			
CO ₂	Y/N			
Is all equipment working	Y/N			
General				
Are there odours	Y/N			
Are flames visible	Y/N			
Is there black smoke	Y/N			
Is noise excessive	Y/N			
Is heat radiation excessive	Y/N			
Are staff formally trained	Y/N			
Is there a flare / engine O & M manual available on-site	Y/N			
Is gas extraction O & M manual available on-site	Y/N			
Are emergency procedures documented in event of flare failure	Y/N			
Are there text alerts or similar to advise when system down	Y/N			
Is there 24 hour emergency callout	Y/N			
Overall Assessment				
Does emissions management from the flare/engine compromise fugitive emissions from site e.g. do units require down time to allow methane concentration to increase	Y/N			
Is there a need for a site specific risk assessment	Y/N			

Note: A checklist should be completed for each individual landfill gas flare and engine at a site.

GLOSSARY

Abatement:	Reducing the degree or intensity of, or eliminating, pollution
Agency:	Environmental Protection Agency
Anaerobic:	In the absence of air
Biodegradable waste:	Any organic waste that is capable of undergoing anaerobic or aerobic decomposition, e.g. food, garden waste, paper and paperboard
Chemiluminescence:	The emission of light during a chemical reaction
Decomposition:	Natural breakdown of materials by the action of microorganisms, chemical reaction or physical processes
Deposition:	Removal of particles or gases from a gas stream through surface adsorption, impaction, etc. In the context of the flare gas emissions, this includes dry deposition -- direct absorption or uptake on soil and vegetation. It may also include wet deposition – removal in rainfall passing through the plume as it disperses
Design capacity:	The maximum gas flow rate the flare is designed to burn at
Duct:	An enclosed structure through which gases travel
Enclosed flare:	Flare in which combustion conditions are improved by enclosure of the flame in a shroud
Environmental impact:	The total effect of any operation on the environment
Flare:	Structure designed to facilitate combustion of landfill gas under controlled conditions
Flue:	See Duct
Fugitive gas:	Proportion of emissions of landfill gas that are not accountable by known point sources on-site. Typically, diffusive loss or leaching through the surface of a landfill generates fugitive losses
Gravimetric:	Method for determination of particle concentrations in air by direct weighing of the mass present in a collected sample
Greenhouse gas:	A gas when present in the atmosphere that contributes to global warming because of its radiative properties
Homogeneous:	A homogeneous mixture is uniformly and completely mixed
Impinger:	Sampling device in which the sample is collected directly into a liquid medium
Intrinsically safe:	Said of apparatus that is designed to be safe under dangerous conditions – usually refers to equipment that can be used in an explosive atmosphere because it will not produce a spark
Isokinetic sampling:	Condition required when sampling particles at which the gas entering a sampling nozzle is at the same velocity and direction as the bulk flow of gas in the sample duct or stack. This condition minimises any sampling error that might arise due to inertial properties of the particles
Landfill gas:	All gases generated from the landfilled waste
LEL (Lower Explosive Limit):	The lowest percentage concentration by volume of a flammable substance in air which will allow an explosion to occur in a confined space at 25°C and normal

atmospheric pressure, and where an ignition source is present (units: %)

Pitot tube:	A probe designed to measure gas velocity in a moving gas stream with minimal disturbance of the flow
Retention time:	The time at which the gases stay within the shroud at, or above, a specific temperature (also known as residence time) (measured in units of time)
Sampling plane:	A plane normal to the centreline of the duct at the sampling position
Sampling point:	The point(s) on the sample plane where the sample is collected
Sampling ports:	Points on the wall of the stack duct or flue through which access to the emission gas can be gained
Stack:	A structure (i.e. chimney) through which emissions is released to atmosphere
Stoichiometric:	The exact proportions in which substances react. For combustion, the theoretical minimum amount of air or oxygen required to consume the fuel completely
NMVOCs (Non-methane Volatile organic compound):	Organic compounds that can be measured in the gas phase at ambient temperature (VOCs) but excluding methane, the predominant VOC in landfill gas
UEL (Upper Explosive Limit):	The highest concentration of mixture of a compound and air which will support an explosion at 25°C and normal atmospheric pressure, and in the presence of a flame
v/v:	By volume (as in % v/v or ppm v/v); usually applied to gases
VOCs (Volatile organic compound)	Organic compounds that can be measured in the gas phase at ambient temperature

ACRONYMS

AMS	Automated Monitoring System
BSI	British Standards Institution
CEMS	Continuous emission monitoring system
CEN	Comité Européen de Normalisation
CH₄	Methane
CO	Carbon monoxide
CO₂	Carbon dioxide
EA	Environmental Agency of England and Wales
ELV	Emission Limit Value
EMS	Engine Management System
EPA	Environmental Protection Agency
EN	Norm Européenne (European Standard)
FID	Flame ionisation detector
FTIR	Fourier transform infrared spectrometry
GC	Gas chromatography
GC-MS	Gas chromatography–mass spectrometry
HCl	Hydrogen chloride
HF	Hydrogen fluoride
H₂S	Hydrogen Sulphide
HSA	Health and Safety Authority
INAB	Irish National Accreditation Board
IR	Infra-red
ISO	International Organisation for Standardization
kPa	Kilopascal
LEL	Lower Explosive Limit
LFG	Landfill Gas
MCERTS	Environment Agency's Monitoring Certification Scheme
MEWP	Mobile Elevated Work Platforms
MS	Mass spectrometry
NMVOC	Non-methane volatile organic compound
NO	Nitric oxide
NO₂	Nitrogen dioxide
NO_x	Nitrogen oxides (sum of NO and NO ₂)
NTP	Normal temperature pressure
PID	Photoionisation detector
PM₁₀	Particulate matter of 10 microns or less in diameter
ppb	Part per billion
PPE	Personal protection equipment
ppm	Part per million
QMS	Quality management system

SSP	Site Specific Protocol
SSRA	Site Specific Risk Assessment
SO₂	Sulphur dioxide
STA	Source Testing Association
STP	Standard temperature and pressure (0°C and 1 atmosphere pressure)
TOC	Total Organic Carbon
UK	United Kingdom
UKAS	United Kingdom Accreditation Service
USEPA	United States Environmental Protection Agency
UV	Ultraviolet
VOCs	Volatile organic compounds

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