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Guidance for monitoring landfill gas engine emissions

LFTGN08 v2 2010

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Foreword

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This guidance is one of a series of documents relating to the management of landfill gas. It is issued by the Environment Agency and the Scottish Environment Protection Agency (SEPA) to be used in the regulation of landfills. It is primarily targeted at regulatory officers and the waste industry. It will also be of interest to contractors, consultants and local authorities concerned with landfill gas emissions. Environment Agency and SEPA officers, servants or agents accept no liability whatsoever for any loss or damage arising from the interpretation or use of the information, or reliance on views contained herein. It does not constitute law, but officers may use it during their regulatory and enforcement activities. Any exemption from any of the requirements of legislation is not implied.

SEPA does not necessarily support and is not bound by the terms of reference and recommendations of other documentation mentioned in this guidance, and reserves the right to adopt and interpret legislative requirements and appropriate guidance as it sees fit.

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The Environment Agency would like to acknowledge the contribution made by the members of the waste industry and the Source Testing Association in developing this guidance. The Environment Agency would also like to thank the operators who allowed access to their sites and the monitoring of equipment.

David Browell Technical advisor

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Appendix

Executive summary

This report is mainly concerned with emissions from spark ignition engines and, in general, does not consider emissions from other forms of landfill gas utilisation such as dual-fuel engines and gas turbines. These other types of engines should be considered on a site-specific basis, drawing upon the principles contained within this guidance. A separate document is available on the monitoring of emissions from landfill gas flares.

This technical guidance draws upon information from collaborative research undertaken by the Environment Agency and the Biogas Association.

In writing this revision of the guidance we have taken account of the results on engine emissions submitted to date. The results show that the industry is able to meet the current standards in a large majority of the cases with well maintained engines.

The data also suggests that when gas is supplied to the engine at the specification recommended by the manufacturer the engines meet the emission standard.

Tables A and B summarise the emission testing requirements for landfill gas engines installed and commissioned:

- between January 1998 and 31 December 2005
- after 31 December 2005.

These emission limits are maximum values and may require adjustment or additional parameters, subject to a risk assessment being undertaken of local parameters. When we assess your compliance against the permit emission limits we will take into account the uncertainty associated with the measurement of the emissions. All emission monitoring should be carried out in accordance with Environment Agency Technical Guidance note M2

Table A Summary of emissions testing requirements for landfill gas spark ignition engines commissioned between 1 January 1998 and 31 December 2005

Emission	**Minimum testing frequency**	**Emission limit**[a]
NOx[b]	Annually	650 mg/m^3
CO	Annually	1500 mg/m^3
Total VOCs	Annually	1750 mg/m^3

a. These limits are based on normal operating conditions and load (temperature 0oC (273 K); pressure: 101.3 kPa; and oxygen: 5 per cent (dry gas). For more information see section on data standardisation. Site-specific risk assessments may require a stricter emission limit to be applied.

b. NOx expressed as nitrogen dioxide (throughout this document)

Engines commissioned and installed before December 1997 should be considered on a site-specific risk basis, and where possible should try and meet the emissions limits specified in Table A.

In addition to the numerical emission limits given in Table A, the following apply:

- Discharges must be vertically upwards and unimpeded by cowls or any other fixture on top of the exhaust.
- Sampling sockets must be fitted to all new installations and it is recommended that they are fitted to existing installations.
- The management of crankcase emissions to minimise their release to the environment is recommended.
- Continuous assessment of methane and flow in the inlet gas is recommended.

Table B Summary of emissions testing requirements for landfill gas spark ignition engines commissioned after 31 December 2005

Emission	**Minimum testing frequency**	**Emission limit**[a]
NOx[b]	Annually	500 mg/m^3
CO	Annually	1400 mg/m^3
Total VOCs	Annually	1000 mg/m^3

a. These limits are based on normal operating conditions and load (temperature 0oC (273 K); pressure: 101.3 kPa; and oxygen: 5 per cent (dry gas). For more information see section on data standardisation. Site-specific risk assessments may require a stricter emission limits to be applied.

b. NOx expressed as nitrogen dioxide (throughout this document)

In addition to the numerical emission limits given in Table B, the following apply:

- Discharges must be vertically upwards and unimpeded by cowls or any other fixture on top of the stack.
- Sampling sockets must be fitted to all new installations.
- Crankcase emissions must be managed to minimise their release to the environment.
- Continuous assessment of methane and flow in the inlet gas must be undertaken.

Recent research using continuous emissions monitoring on landfill gas engines indicates there is significant upward drift in emissions between annual assessments (Golder Associates 2006; Environment Agency). Therefore, we now require you to undertake additional monitoring to reduce the time between compliance assessments. This monitoring should be carried out using suitable portable instruments in accordance with the procedure set out in Appendix C. You should monitor the NOx and CO emissions and re-tune the engine to ensure that the emissions are within the appropriate limits.

1. Setting the scene

We have produced a standard set of monitoring methods to allow us to collect emissions data in a transparent and consistent way. Emissions from landfill gas engines are different to those of other spark-ignition engines due to the different fuel source. As a result, we've designed the standards to reflect these differences. This document details the emissions standards all landfill gas spark ignition engines must meet.

This guidance is concerned primarily with emissions from spark ignition engines and, generally doesn't consider emissions from other forms of landfill gas use. Other types of engines should be considered on a site-specific basis, but the aim should be to apply the principles contained within this guidance.

A site-specific risk assessment may identify a need for stricter emissions standards or additional parameters than those listed in tables A and B.

1.1 Structure of this document

This is one of a series of linked documents that support the overarching document, Guidance on the management of landfill gas (Environment Agency). The full series comprises:

- Guidance for monitoring trace components in landfill gas
- Guidance for monitoring enclosed landfill gas flares
- Guidance for monitoring landfill gas engine emissions
- Guidance for monitoring landfill gas surface emissions
- Guidance on gas treatment technologies for landfill gas engines.

1.2 Landfill gas - the issues

Landfill gas is an inevitable by-product of anaerobic decomposition of organic waste. Because of its high combustible gas content it is a potentially valuable energy source. To overcome concerns relating to public health and environmental protection, landfill operators should collect and dispose of landfill gas in an environmentally safe manner.

Gas collection has traditionally been undertaken using collection wells within the landfill. When not used as a fuel, landfill gas is usually flared at high temperatures – a process that destroys most of the toxic and odorous components. Passive venting of landfill gas to the atmosphere is no longer acceptable. At all landfills, some gas does escape to the atmosphere through the site's surface and lining. The percentage of fugitive gas will depend primarily on the collection efficiency on-site, the lining design, the site capping and the volume of gas generated.

1.2.1 The Landfill Directive

Annex I of the Landfill Directive (Council of the European Union, 1999) sets out a clear obligation to safely manage and minimise landfill gas emissions. The technical requirements of the Landfill Directive have been implemented in England and Wales by the Environmental Permitting Regulations (England and Wales) 2010 and in Scotland via the Landfill (Scotland) Regulations 2003.

The Regulations require the following gas control measures:

- appropriate measures must be taken in order to control the accumulation and migration of landfill gas;
- landfill gas must be collected from all landfills receiving biodegradable waste. The gas must be treated, and used wherever possible;
- the collection, treatment and use of landfill gas must minimise damage to or deterioration of the environment, and risk to human health;
- landfill gas which can't be used to produce energy must be flared.

1.2.2 Renewables Policy

The Renewable Energy Directive (2009/28/EC) sets a national target of 20 per cent of the UK's energy from non-fossil sources by 2020. The Government's renewables policy has two main strands with respects to landfill gas electricity generation

Non-Fossil Fuel Obligation (NFFO)
The Non-Fossil Fuel Obligation (NFFO) framework was established as part of the Electricity Act 1989 to ensure renewable energy sources could compete in the open market. Under this Act, the Secretary of State made five orders requiring the regional electricity companies (RECs) to contract certain amounts of electricity-generating capacity from renewable sources (including wind, water and waste materials). There have been five NFFO orders to date. The first two orders, NFFO 1 and NFFO 2 started in 1990 and 1992, respectively, and ended at the end of 1998. Contracts under the remaining three orders, NFFO 3 (1995), NFFO 4 (1997) and NFFO 5 (1998) will continue for many years, with the last contract terminating in 2018.

Renewables Obligation
As part of it's revised policy for renewable energy in the UK, the Government introduced the Renewables Obligation for England and Wales (known as Renewables Obligation (Scotland) for Scotland) as a successor to the NFFO. This obligation, introduced by the Utilities Act 2000, requires power suppliers to derive a specified proportion of the electricity they supply to their customers from renewable resources. It also introduced transitional arrangements for NFFO 3, 4 and 5.

Compliance with the Renewables Obligation is demonstrated by presenting Renewables Obligation Certificates (ROCs) to the Office of Gas and Electricity Markets (Ofgem) at the end of each compliance period. Suppliers may also fulfil all, or part of their obligation by paying Ofgem a buyout price for each kWh short of their target. The buyout price is linked to the retail price index (RPI), with the revenue raised being returned to the suppliers in proportion to the number of ROCs they've presented to discharge their obligation. This approach is intended to provide a strong financial incentive for suppliers to fulfil the Renewables Obligation through ROCs rather than simply buying out.

Further information on the Renewables Obligation and UK renewables policy can be found on the Department for Business, Innovations and Skills website www.bis.gov.uk

1.3 Landfill gas composition and energy recovery plant

1.3.1 Landfill gas constituents

The Landfill Directive defines landfill gas as: 'all the gases generated from the landfilled waste'.

The chemical composition of landfill gas is variable, but mature landfill gas is commonly a mixture predominantly made up of methane (CH_4; generally 60 to 35 per cent volume/volume) and carbon dioxide (CO_2; 35 to 60 per cent v/v). It will also contain trace concentrations of a range of vapours and gases.

Landfill gas consists of two distinct fractions:

- The bulk fraction is a mixture of methane, carbon dioxide, hydrogen, nitrogen and oxygen. These are measured in terms of percentage by volume.
- The trace fraction is a wide range of volatile and semi-volatile organic compounds that are measured in terms of parts per million (ppm) or parts per billion (ppb). Over five hundred trace components have been identified in landfill gas, comprising up to one per cent of the gas by weight (about 0.1 to 0.35 per cent by volume) (Environment Agency).

There have only been a limited number of studies investigating the emissions from landfill gas combustion processes. However, it is apparent that emissions can be highly variable from plant to plant and at different periods of operation within the same plant. Primary emissions are nitrogen, carbon dioxide, sulphur dioxide (SO_2), oxides of nitrogen and water vapour. In the case of sulphur dioxide, emission concentrations depend primarily on sulphur-containing compounds in the landfill gas. Hydrogen sulphide (H_2S) may be a significant component and this may have implications for local air quality. Dual-fuel engines that use diesel in combination with landfill gas often emit higher concentrations of hydrogen sulphide and sulphur dioxide than spark ignition engines.

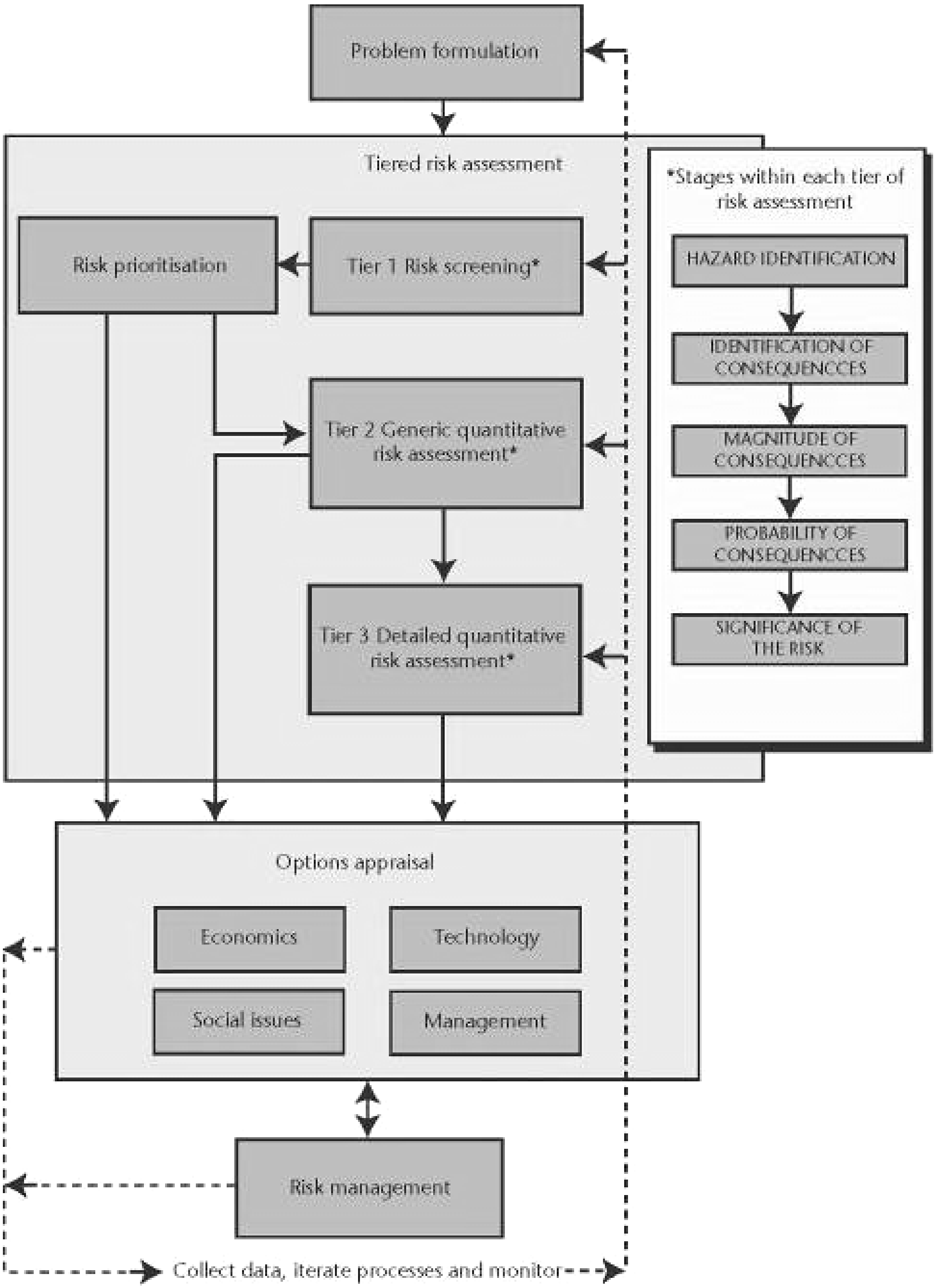
In addition to the compounds indicated above, a number of trace components are emitted, including heavy metals and volatile organic compounds (VOCs). Trace quantities of metals will be present in both the elemental and compound form (for example, As, Cd, Cr, Cu, Pb, Mn, Hg, Ni, Sn, Zn). Trace quantities of a number of compounds with potential health impacts may also be emitted, with dioxins and furans of particular interest (Fielder, 2001).

1.4 Environmental risk assessment

Figure 1.1 provides a framework for a tiered approach to assessing and managing environmental risk. This approach ensures the level of effort put into assessing each risk is proportionate to its priority (relative to other risks) and its complexity (relative to an understanding of the likely impacts). Guidelines for environmental risk assessment and management (DETR et al., 2000) should be consulted before undertaking any risk assessment.

Data on priority trace gas composition will be required to undertake a satisfactory risk assessment and to determine a site-specific emission standard. Guidance on carrying out a risk assessment is given in Horizontal Guidance Note EPR H1 (Environment Agency) and Guidance on the management of landfill gas (Environment Agency). Factors that may be considered include:

- topography
- location of receptors
- landfill gas quality
- size, number and age of engine and flare installations
- single or multiple exhausts
- emission height (see Environment Agency).



Source: DETR et al. (2000)

Figure 1.1 A framework for environmental risk assessment and management

2. Emission Standards

2.1 The need for emission standards

Local Air Quality Management & EU Air Quality Directives

The Government's Air Quality Strategy[1] (AQS) establishes the Local Air Quality Management (LAQM) regime and sets air quality standards and objectives for 9 pollutants, 7 of which are specified in regulations (benzene; 1,3 butadiene; carbon monoxide; lead; sulphur dioxide; nitrogen dioxide; PM10). Objectives are in the form of an ambient concentration for a substance, measured over a period of time, to be achieved by a certain date. Many of these objectives replicate EU limit values although the timing to achieve them may be different. National objectives and EU limit values apply at locations where people are exposed for a period of time that is relevant to the standard (guidance is available in Defra's publication LAQM.TG(09).

Table 2.1 UK air quality objectives and European Directive limit values for the protection of human health and ecosystems

Pollutant	**Date to be achieved by and maintained thereafter**		**Criteria based on**	**Value**
	UK objectives	**EU limit value**		**µg/m^3**
Nitrogen dioxide	31 December 2005	1 January 2010	1-hour mean. Not to be exceeded more than 18 times per calendar year.	200
	31 December 2005	1 January 2010	Annual mean	40
	31 December 2000	19 July 2001	Annual mean NO_x vegetation guideline	30
Sulphur dioxide	31 December 2005	Not applicable	15-minute mean. Not to be exceeded more than 35 times per calendar year.	266
	31 December 2004	1 January 2005	1-hour mean. Not to be exceeded more than 24 times per calendar year.	350
	31 December 2004	1 January 2005	24 hours (daily mean). Not to be exceeded more than 3 times per calendar year.	125
	31 December 2000	19 July 2001	Calendar year annual mean vegetation guideline.	20
	31 December 2000	19 July 2001	Winter mean vegetation guideline.	20
Benzene	31 December 2003	Not applicable	Running annual mean	16.25
	31 December 2010 England/Wales	1 January 2010	Annual mean	5
PM_{10}	31 December 2004	1 January 2005	24 hours (daily mean). Not to be exceeded more than 35 times per calendar year.	50
	31 December 2004	1 January 2005	Calendar year annual mean	40
Carbon monoxide	31 December 2003	1 January 2005	Running 8-hour mean	10,000 (10 mg/m^3)

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[1] The Air Quality Strategy for England, Scotland, Wales and Northern Ireland, Defra 2007

Source: DEFRA (2007)

The Environment Act 1995 requires that the Agency "has *to have regard to the Government's Air Quality Strategy in discharging its pollution control functions*".

The Agency has committed to ensuring that no EPR waste facility or installation it regulates will contribute significantly to breaches of an AQS objective. This principle also applies for EU air quality limit values but for EPR, compliance with EU limit values is mandatory.

The Government's Air Quality Strategy indicates that it does not expect the Agency will require an operator to go beyond BAT in EPR permitting in order to achieve a national objective. The Agency's interpretation of this aspect reflects the requirement of Defra Guidance on Environmental Permitting: The IPPC Directive. And if a national objective is likely to be breached, then controls may need to be more stringent to protect the local environment than for an installation in other areas which do not have an air quality problem.

However, in the case of where an EU limit value could be breached, the Agency must set more stringent emission limits or other controls than would be the case under BAT, if they are needed to achieve compliance where the installation is making a significant contribution.

The implementation of Waste Framework Directive through the EPR regulations does not specifically refer to the AQS. And so the duty on operators to apply best practice "*to ensure that waste is managed properly, recovered or disposed of safely and does not cause harm to human health or pollution of the environment*" is most relevant. In effect this means the same requirements apply for achieving national objectives and EU limit values as apply via IPPC legislation.

The AQS also includes an EU limit value of 30 μg/m^3 as an annual average for total nitrogen oxides (as NO_2) to protect vegetation. This was to be achieved by 31/12/00 but only applies to parts of the UK namely: more than 20 km away from agglomerations or more than 5 km away from other built-up areas, industrial installations or motorways or major roads with traffic counts of more than 50,000 vehicles per day. Therefore this objective will only be relevant to landfill gas engines in a limited number of situations solely for the purposes of air quality legislation. However this vegetative standard provides a measure of 'harm' and should be taken into account in determining EPR permit conditions. The Environment Agency and Natural England (Countryside Council for Wales CCW) have also agreed to apply this standard for appropriate assessments carried out for the purposes of the Habitats Regulations (Natura 2000 sites) or CROW (SSSIs).

The above commitments apply to landfill engines which are currently operating, as well as ones which will be installed in the future.

2.2 Other Emission Legislation

The Gothenburg protocol also imposes emission limit values from defined technologies

Table 2.2 Emission limit valves (ELVs) for NOx for new installations set by the Gothenburg Protocol

Equipment		**NOx emissions (mg/m^3)**
Spark ignition	Lean burn engines	250
	All other engines	500

Note: Values are referenced to 5 per cent oxygen and apply to engines running >500 hours/year.

The Gothenburg Protocol does not currently apply to ELVs for landfill gas engines in the UK because the Government did not adopt that part of the 1999 version of the Protocol. However the terms of the Protocol are currently under review and are likely to include landfill gas engines in the future.

2.3 Emission standards for Spark Ignition Landfill gas Engines

The majority of landfill gas engines in the UK are modern, turbocharged spark-ignition (SI) internal combustion engines. However, the emissions associated with a landfill gas engine are different to those of other spark ignition engines. This is primarily due to the fuel source and this necessitates applying different specific emission standards to this class of engine.

The primary pollutants of concern emitted from landfill gas engines are oxides of nitrogen (NOx), carbon monoxide (CO) and volatile organic compounds (VOC) which consists of unburnt methane. We set emission standards for these primary pollutants in your permit. However there is also a proportion of other volatile organic compounds emitted, referred to as non-methane volatile organic compounds (NMVOC). We previously set an emission limit for total NMVOC in permit conditions however this monitoring requires speciation of the constituent NMVOC before it can be quantified. Due to changes in monitoring methods, there is no longer a suitable reference method available for monitoring total NMVOCs, which means this monitoring cannot be carried out on landfill gas engines.

We have adopted a tiered approach to forming emissions standards for landfill gas engines to reflect the date the engines were commissioned and the emissions associated with a well constructed, maintained and operated landfill gas spark ignition engine (Biogas Association, 2002; Environment Agency). The generic emission standards are given in Tables 2.3 and 2.4 below and should be regarded as the minimum standard we expect from landfill gas engines.

However, all engines should be considered on a site-specific risk basis and may necessitate a stricter emission standard either in terms of the generic emissions standard stated below (for example, reducing NO_x from 500 to 400 mg/m^3) or in terms of additional parameters. This determination should be based on risk and the impact that the engine may have on health, environment or amenity. You should use the guidance provided in Horizontal Guidance Note EPR H1 (Environment Agency) to make this determination. You should also consider a typical raw landfill gas (for example, elevated levels of chlorinated compounds) and assess dispersion modelling (for example, a potential breach of a UK air quality objective or EU limit value).

2.3.1 Review of Emission Standards

Since the engine emissions standards were first introduced in the previous version of this guidance, developments in engine technology have focussed on improving efficiency and power-to-emissions ratios, rather than improving specific emissions. In conjunction with the waste industry, we have reviewed the performance of landfill gas engines that were commissioned both pre and post 2006 by looking at the results of emissions monitoring. We found that engines, commissioned between 1 January 1998 and 31 December 2005, are capable of meeting the emission standards in Table 2.3.

However there was some uncertainty that engines commissioned after 1 January 2006 are capable of achieving consistent NOx emissions below the standards in Table 2.4. Just under 50% of the engines tested met the NOx emission limit however a further 35% of the engines were approaching the emission limit when the measurement uncertainty was taken into account. This was based on a relatively small number of emissions tests which reflects the fact that the majority of landfill gas engines were commissioned before 1 January 2006. Furthermore it is unclear how these overall results are affected by individual engine maintenance schedules and whether pre-treatment of the inlet gas brought the engine emissions into compliance.

A more comprehensive review into the emissions from these newer engines is required before any variation to the emission standards in Table 2.4 can be considered.

VOC emissions are mainly unburnt methane from slippage through the engine. These emissions are inversely proportionate to the NOx and carbon monoxide (CO) emissions from the engines and it can be difficult to maintain compliance with NOx, CO and VOC emission limits simultaneously without reducing engine efficiency and power output. However given that the emission of unburnt methane through the engines can be a significant contribution to methane emissions from landfill (typically 2% of throughput through engines) we do not intend to remove this emission limit. Overall compliance with this emission limit does not appear to be an issue although engines will have an individual emissions profile depending on site specific factors such as inlet gas quality and maintenance schedule.

The review of emissions testing has shown that the previous limits for NMVOC were not exceeded. Coupled with the change in monitoring methodology we have removed the NMVOC emission limit.

In a 2002 study, the Biogas Association quantified crankcase breather emissions (Biogas Association, 2002). These emissions can be significant in terms of total unburnt hydrocarbons and SO_x, at up to 30 per cent of the exhaust mass emission rates. However, CO and NO_x emission rates were <1 per cent of those from the engine exhaust. A variety of best practice options to reduce these emissions exist such as recirculating leakage from the engine container back for further combustion (Environment Agency).

The following sections set out the revised emission standards for landfill gas SI engines.

2.3.2 Landfill gas engines commissioned before 31 December 1997

All these engines should be considered on a site-specific risk basis and the emission standards should be determined based upon the impact that they may have on health, environment or amenity. This determination should be based on the guidance provided in Horizontal Guidance Note EPR H1 (Environment Agency) and the emission standards given Table 2.3. The recommendations concerning discharges and sampling sockets contained in Section 2.3.3 should also be followed as best practice.

2.3.3 Landfill gas engines commissioned between 1 January 1998 and 31 December 2005

All engines should be designed, operated and maintained to comply with emission standards given in Table 2.3.

Table 2.3 Emission limits for spark ignition landfill gas engines (commissioned between 1 January 1998 and 31 December 2005)

Parameter	Emission standard (mg/Nm^3)^{1,2}
NO$_x$	650
CO	1500
VOCs	1750

1) All emissions are reported under the following conditions. Temperature 0^{0}C (273K), pressure 101.3 kPa, and oxygen 5% (dry gas).

2) Standards are based on normal operating conditions and load. Site-specific risk assessments may require a stricter limit to be applied.

In addition to the numerical emission standards given in Table 2.3, the following descriptive conditions also apply:

- Discharges must be vertically upwards and unimpeded by cowls or any other fixture on top of the exhaust (see Section 4.2).
- Sampling sockets (see Section 4.2.2) must be fitted to existing installations.
- We recommend managing crankcase emissions to minimise their release to the environment.
- We recommend continuous assessment of methane and flow in the inlet gas.

2.3.4 Landfill gas engines commissioned after 31 December 2005

All engines should be designed, operated and maintained to comply with emission standards in Table 2.4.

Table 2.4 Emission limits for spark ignition landfill gas engines (commissioned after 31 December 2005)

Parameter	Emission standard (mg/Nm^3)^{1,2}
NO$_x$	500
CO	1400
VOCs	1000

1) All emissions are reported under the following conditions. Temperature 0^{0}C (273K), pressure 101.3 kPa, and oxygen 5% (dry gas).

2) Standards are based on normal operating conditions and load. Site-specific risk assessments may require a stricter limit to be applied.

As with earlier commissioned engines, engines commissioned after 31 December 2005 must also comply with the descriptive conditions listed in 2.3.3.

2.4 Additional Emission Standards

The above emission standards will be set in your permit, however each landfill gas engine should be assessed on an individual site basis depending on the trace components in the landfill gas, possible combustion products and the results of your landfill gas risk assessment and air dispersion modelling. We will assess the need for any additional parameters to be considered at the permit application stage and at subsequent permit reviews over the life of the site. As a result of these permit reviews, we may require you to carry out emissions monitoring for additional substances to inform further risk assessment work. We may also set emission limits on these parameters in your permit conditions on a site specific basis. An example would be where there is high sulphur content of the inlet landfill gas which may result in high sulphur dioxide emissions.

We may require additional monitoring and assessment for the following pollutants:

- Sulphur dioxide
- Hydrogen sulphide
- Dioxins (PCDD and PCDF)
- Heavy metals
- Halides and acid gases such as hydrochloric acid or hydrofluoric acid
- Particulates

2.5 Commissioning and Relocation of Landfill Gas Engines

The above emissions standards apply to engines based on the date they were commissioned. For the purposes of this guidance commissioning is taken to mean the date when the engine was first installed at any site and was used to generate electricity. Engines commissioned before 1 January 2006 are unable to achieve the post 2006 emission limits in Table 2.4.

It is not sustainable to require all engines installed on a site after 1 January 2006 to meet the emission standard in Table 2.4. To do so would result in a large proportion of serviceable engines being unusable which is not consistent with BAT given the cost of the engines against the reduced emissions. It is also commonplace within the industry to relocate engines to match generation capacity with gas generation, to replace mechanical failures, and to exchange engines during major service overhauls. An operator may therefore have a fleet of engines that over their service lifetime are deployed at several installations depending on operational requirements.

Where you intend to remove an engine and relocate it, you must justify the removal of the engine from the initial site to show that you cannot use the landfill gas to generate energy and that the requirements of Annex 1 of the Landfill Directive are met. This is not required when you are replacing an engine as part of a major service or as a result of mechanical failure.

We need to ensure that this redeployment of engines of various ages does not impact on the environment and that wherever possible measures are taken to improve emissions from EPR installations. For all new installations after April 2010, we expect all the engines at that installation to comply with the emission standards in Table 2.4.

For all other installations relocation of engines, commissioned between 1 January 1998 and 31 December 2005, is permissible under the following conditions:

- To replace an existing engine, providing the replacement engine can meet the same emission standards as that existing engine
- To replace an existing engine, where the replacement engine can meet a lower emission standard.
- To increase generation capacity at an existing installation providing the risk assessment shows there will be no adverse impact of air quality as a result of the higher emissions
- No engines that were commissioned prior to 31 December 1997 can be relocated.

Where an engine has been relocated to a site then you will need to carry out emissions testing of that engine at the site to demonstrate that the engine meets the emission limits. We would expect this testing to take place within 6 months of the engine being relocated, thereafter the emissions testing can revert to an annual basis.

2.6 Other Engines

The above emission standards were derived for larger spark ignition engines. Increasingly smaller capacity spark ignition engines (<250KWe), turbines and micro turbines are being used to maximise utilisation of landfill gas.

Gas turbine engines effectively operate as air pumps, and therefore have different emissions characteristics to turbocharged spark-ignition engines. We included no specific emissions standards or monitoring methods for gas turbines in the previous version of this guidance. However you should monitor for NOx, CO and VOC in the exhaust emissions from gas turbines and micro-turbines at least annually using an appropriate method based on the design and specification of the turbine.

You should use three sets of reporting conditions when reporting emissions from gas turbines and microturbines.

- Normalising the data to 5% O_2 allows comparison with emissions from other landfill gas engines,
- Normalising to 15% O_2 allows comparison with the emission limits for gas turbines in Process Guidance Note PG1/4(95) (HMIP, 1995)
- You should also report gas turbine emissions in grams per hour (g/hr) for each determinand listed in Tables 2.4. Base your calculations on a theoretical determination of the volumetric exhaust flow rate derived from the manufacturer's specifications and methane input together with the measured temperature.

The impact of small SI engines, gas turbines and micro turbines should then be assessed on a site specific basis in accordance with Horizontal Guidance Note EPR H1 (Environment Agency). At the moment (2010) we do not intend to impose specific emission limits on these engines other than the mass release of pollutants from these engines should not exceed the comparable mass release from an engine meeting the emission standards in Table 2.4.

3. Site-specific issues

3.1 Health and safety

Neither the Environment Agency or SEPA regulate health and safety at work. We've issued this guidance as advice to those required to monitor landfill engine emissions. Any health and safety issues should be discussed with the Health and Safety Executive (HSE). Further detail on monitoring safely is given in our publication :

- M1 - sampling requirements for stack emissions monitoring

3.1.1 Safety requirements

Health and safety is of paramount importance when undertaking any engine emissions programme. It is a legal requirement for a health and safety risk assessment to be carried out before any test work is undertaken (see Section 4.1.2). A risk assessment considers the levels of risk from any hazards present on a site and identifies what measures are needed in order to minimise the safety risk. A preliminary site review should be undertaken before any engine emissions monitoring exercise.

Each site will have site-specific issues and the risk assessment should assess the risks associated with:

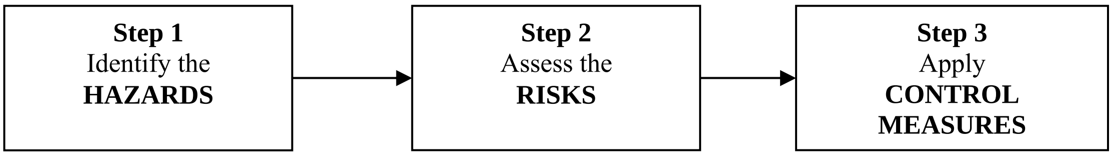
- the testing site location
- sampling positions
- site/test area access
- logistical requirements.

The risk assessment should be updated to account for any changes to the working plan in the site's method statement. Safety requirements must take priority over any other factor in a testing programme.

3.1.2 Health and safety guidance and regulations

The Health and Safety at Work Act 1974 places a duty on employers to have a safety policy and to carry out risk assessments for any work programme. Any work being carried out to the Environment Agency's Monitoring Certification Scheme (MCERTS) standards (Environment Agency) also require a risk assessment to be produced. Technical Guidance Note M1 (Environment Agency) provides detailed guidance on assessing safety requirements on a test site.

The fundamental stages of the risk assessment process are:



It is vital to understand the difference between hazard and risk:

- a hazard is a substance or physical situation with inherent potential to cause harm;
- risk is an estimation of the likelihood of that potential being realised, within a specified period or in specified circumstances, and the consequence.

The Source Testing Association also publishes guidelines on the hazards and risks relating to stack testing (STA a), which describe general hazards and potential risks associated with testing. It has also produced example risk assessments for stack sampling operations (STA b), which provides guidance on the issues to be aware of when undertaking emissions testing.

The MCERTS performance standard for organisations carrying out manual stack emissions monitoring includes an annex detailing requirements for undertaking a risk assessment prior to stack emissions testing (Environment Agency). This guidance should be consulted as part of the risk assessment process.

4. Emission monitoring.

4.1 List of required test parameters and methods

The parameters to be monitored during emissions testing of landfill gas engines will be specified in your EPR Permit. The methodologies to be used when carrying out the monitoring should be taken from Part II of Technical Guidance Note M2 (Environment Agency). Technical Guidance Note M2 is continually updated and reference should be made to the most recent version to ensure that appropriate methods are used.

4.2 Testing frequency

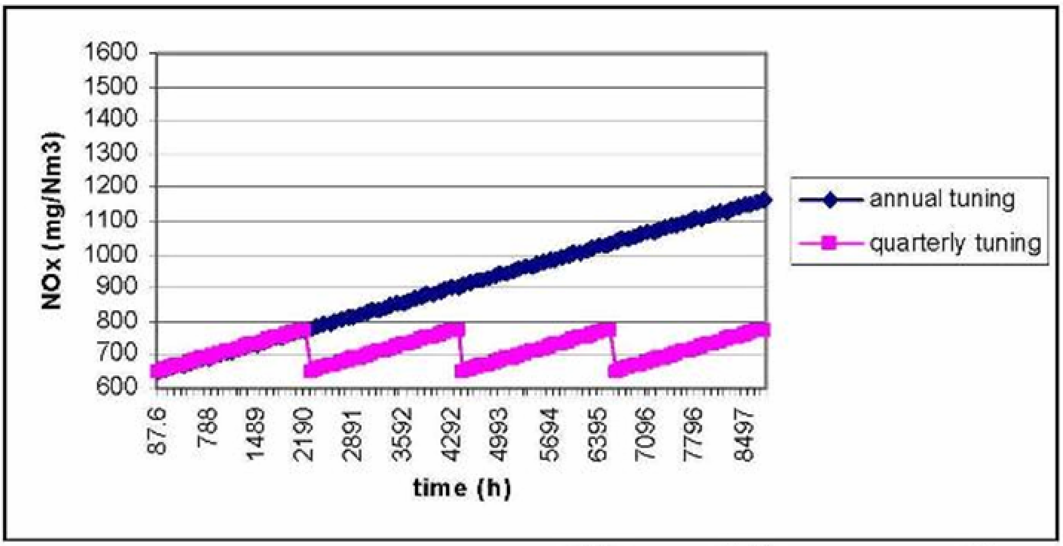
The test frequency for engine emissions should always be based on an individual site assessment. In the past, we allowed operators with well-established emissions profiles to reduce their engine monitoring to once per year. As a minimum, you will still need to carry out an annual emissions compliance test using the methods in Technical Guidance Note M2

However, recent research using continuous emissions monitoring on landfill gas engines indicates there is significant upward drift in emissions between annual assessments (Golder Associates 2006; Environment Agency). Therefore, we now require you to undertake additional monitoring to support your annual emissions compliance test This supplementary monitoring should be carried out using suitable portable instruments, in accordance with the procedure set out in Appendix C. You should monitor the NOx and CO emissions and re-tune the engine to ensure that the emissions are within the appropriate limits.

You should use your site-specific knowledge of engine drift rate to determine an appropriate assessment interval. We will require you to report this information to us quarterly, and as a minimum we would expect you to carry out this testing on a quarterly basis. However depending on the characteristics of the inlet gas and the individual engine a more increased frequency may be required if monitoring shows the engine emissions drift.

You can achieve a significant environmental benefit in terms of NO_x emissions by moving to more frequent compliance assessments. Figure 4.1 schematically represents the reduction in NO_x emissions possible as a result of quarterly engine compliance assessments and tune-ups.

Figure 4.1 Schematic representation of the linear increase in NO_x with time for annual and quarterly engine compliance monitoring assuming linear drift



This data assumes an engine commissioned to achieve the 650 mg/Nm^3 NO_x emission standard. It undergoes a drift to 800 mg/Nm^3 within three months. This representation shows a NO_x reduction of approximately 20% as a result of moving to quarterly assessments.

4.3 Quality assurance of monitoring (MCERTS)

All annual compliance monitoring of engine emissions must be carried out using MCERTS accredited organisations, using the methods detailed in TGN M2. You should report the results to us using the format shown in Appendix 1.

To support annual compliance monitoring additional routine maintenance and quarterly monitoring using handheld portable instruments is required. MCERTS accreditation or certification is not required for the organisations or individuals who perform this additional monitoring. However, MCERTS certification is required for the portable handheld monitoring instruments used.

We recognise there is currently (April 2010) a limited number of portable handheld monitoring instruments which conform to the MCERTS standard for portable handheld instruments. Therefore, we expect all portable instruments used for routine maintenance and quarterly monitoring to conform to MCERTS by the end of 2011.

All handheld portable instruments used for routine maintenance and quarterly monitoring must be regularly calibrated according to their manufacturer’s instructions.

Any portable instruments used for routine maintenance and quarterly monitoring must be cross calibrated annually with MCERTS accredited compliance monitoring.

4.4 Standardising data

All monitored data should be reported according to the set of standard reference conditions given in Table 4.1. Appendix A contains an example of a standard report format that will allow easy interpretation and comparison of results. Where possible, you should send an electronic version of your monitoring results to us. If you wish to use an alternative reporting format, you should agree it with us beforehand.

To convert the measured emissions concentrations to the reference conditions, you must apply a series of correction factors to the data. These correction factors are given in more detail in Technical Guidance Note M2 (Environment Agency).

Table 4.1 Standard reference conditions for reporting landfill gas engine emission monitoring data

Parameter	**Standard reference value**
Temperature	0°C (273K)
Pressure	101.3 kPa
Oxygen	5 per cent (dry gas)

4.5 Compliance assessment

The four recognised types of monitoring used to measure emissions are:

- continuous – a complete series of measurements covering all operating conditions;
- periodic – intermittent measurements covering different conditions of normal operation;
- group – a number of measurements made under the same operating conditions;
- individual – lone measurements, which are not part of a group.

The emissions standards presented in this guidance are derived from measurements collected at a range of landfills and from a number of different engine designs operating under normal conditions.

This guidance on monitoring only requires periodic measurement to determine the emissions profile of the generating set. Inevitably, the annual and quarterly monitoring covers only a small period in the emissions from the engine and, consequently, it is necessary to assume the periodic measurement is representative of operation outside the monitoring period.

Increased confidence in this assumption can be provided by developing an emissions profile for the engine. You may build up this profile over time, for example, by making targeted measurements under a range of conditions encountered during normal operation. You can also use surrogate determinands and operational information (such as, methane and flow) to confirm the engine’s consistent operation.

If the operational information during the monitoring period differs substantially from that recorded during the preceding months, sampling will be unrepresentative of the earlier operation. It will only be representative of future operations if the operating profile does not change.

The quality and consistency of the representative samples is best assured by using the standard techniques outlined in this guidance.

When assessing compliance against engine emissions standards, we must take into account the representative nature and reliability of the measured values. Any measurement uncertainty should include the analytical uncertainty estimates which follow CEN guidance. These uncertainties are considered below.

4.5.1 Measurement uncertainty

A number of different uncertainties (such as, uncertainty from sampling position, sampling equipment, analytical equipment and chemical/physical uncertainty) have to be combined to assess the overall measurement uncertainty.

The overall measurement uncertainty is calculated by:

- defining the steps of a measurement
- identifying the sources of uncertainty associated with these steps
- quantifying the respective uncertainties
- combining these uncertainties.

The component uncertainties are combined using the following formula, which involves taking the square root of the sum of the squares of the individual uncertainties, that is:

$$U_{combined} = \sqrt{\left(u_1^2 + u_2^2 + u_3^2 + ...u_n^2\right)}$$

Each measurement and it's associated uncertainty must be determined within a known confidence limit, that is, there is confidence the interval chosen does contain the real value. For emission measurements associated with landfill gas engines, the chosen confidence level is 95 per cent.

Wherever possible, the specific uncertainty in a set of monitoring measurements should be reported and used in the assessment. A method for calculating uncertainty is given in the *Guide to the expression of uncertainty in measurement* (ISO, 1995). However, where uncertainties can't be reasonably estimated, the guidance below can be used to derive typical acceptable values. **Errors and uncertainty greater than those given in Table 4.7 below, generally indicate nsatisfactory monitoring.**

Where methods are in accordance with a recognised measurement standard, the measurement uncertainty will be better understood. Table 4.5 gives the quoted uncertainty for the methods referenced in this guidance.

The uncertainties quoted in Table 4.5 apply only when the measurement complies fully with the standard method. However, the design and operation of landfill gas engines means it is not always possible to perform fully compliant emission tests, consequently the measurements will have a different uncertainty from those quoted in the measurement standards. An overall measurement uncertainty will then have to be calculated.

Table 4.5 Measurement uncertainty for methods used in monitoring emissions from landfill gas engines

Determinand	**Method description (refer to M2 Guidance Note)**	**Typical uncertainty value based on CEN SRM (per cent)**
Nitrogen oxides	Extractive chemiluminescence	10
Carbon monoxide	Extractive non-dispersive infra red	6
Total volatile organic compounds	Flame ionisation detection	20

4.5.2 Monitoring instrument interferences

It is also important to be aware of the potential for interference on particular types of monitoring instruments used to measure exhaust emission concentrations.

The potential for 'cross-sensitivity' exists and some species other than those of interest can affect the measurement, with either a positive or negative interference. For example, two analysers (A and B) from different manufacturers, both using non-dispersive infra-red (NDIR) to measure sulphur dioxide, show different interferences with methane. Table 4.6 gives these interferences as stated by the manufacturers. It is clear that, for a site emitting 1,000 ppm of methane, analyser B will significantly over-estimate the reading for SO_2 compared with analyser A.

Due to the complexity of the fuel source, landfill gas engines have the potential to emit a wide range of substances. This can give rise to a number of species with the potential to interfere with the monitoring instruments. The instrument manufacturer, experienced testing teams and instrument technicians should all be aware of potential interferences that may affect the monitoring instruments and should be able to advise on the suitability of using particular analysers (before any sampling is carried out).

Table 4.6 Typical Interferences with methane

Analyser	Methane content in gas to be measured	Interference with reading of SO_2
A	1%	14 ppm
B	0.1%	78 ppm

4.6 Assessing compliance

Assessing compliance of the measured values against the emissions standards can be divided into four stages:

- confirmation of evidence
- determination of compliance with emission standard
- reporting
- consideration of response.

The operator is normally responsible for the first three stages, while we assess the report and consider the response.

4.6.1 Confirmation of evidence

The quality and representative nature of the measurements have to be considered in order to ensure the data is within the scope covered by the limit value. Questions you need to address include:

- Is the data of adequate quality?
- Have the correct monitoring methods been used?
- Have the monitoring methods been used correctly?
- Have there been any deviations from the recommended monitoring methods? If so, are these justified and what effect have they had on the quality of measurement?
- Does the emission profile indicate that the periodic sample was representative?

If you can’t answer any of these points satisfactorily, the data may be inadequate for a full compliance assessment and further action may be required to achieve representative monitoring.

The reported uncertainty in measurements doesn’t consider the variability of the emissions between the periodic monitoring. The uncertainty arising from unrepresentative sampling periods will be site-specific and is likely to change during the operational period at the site.

Where you can deduce this uncertainty from the emission profile, you should state it and add the additional uncertainty to the measurement uncertainty. We will then use this calculated total uncertainty to assess compliance.
Where you can’t deduce it, we will assume the total uncertainty, including that related to the representative nature of the measurements will not exceed the values given in Table 4.7. These values are based on:

- the degree of uncertainty identified in the standard methods
- guidance from relevant directives
- Environment Agency research data on monitoring engines.

If the calculated total uncertainty exceeds these values, it will generally indicate unsatisfactory monitoring or erratic engine performance.

Table 4.7 Assumed maximum values for total uncertainty to be applied when assessing compliance of emissions from landfill gas engines

Determinant	CEN Method description	Maximum uncertainty (%)
Nitrogen oxides	Extractive chemiluminescence (BS EN 14792)	30
Carbon monoxide	Extractive non-dispersive infra red (BS EN 15058)	20
Total volatile organic compounds	Flame ionisation detection (BS EN 12619)	40

4.6.2 Determination of compliance with the emission standard

All monitoring data is subject to error and uncertainty, and a determination of compliance must take account of this. The fundamental principle is that the emission standard itself is fixed and any allowance for uncertainty is associated with the monitoring data. Assessing compliance of landfill gas engine emissions is subject to the general principles applied to the regulation of other emissions.

- **Compliance**. All measurements giving outcomes that are within the standard, irrespective of uncertainty, we will regard as compliant.
- **Approach to limit**. All measurements giving outcomes that are above the standard, but by an amount that doesn't exceed the uncertainty, we will regard as approaching the limit. We will deem these compliant.
- **Non-compliance**. All measurements giving outcomes that are above the standard after subtracting the uncertainty, we will regard as non-compliant.

These situations are illustrated in Figure 4.2.

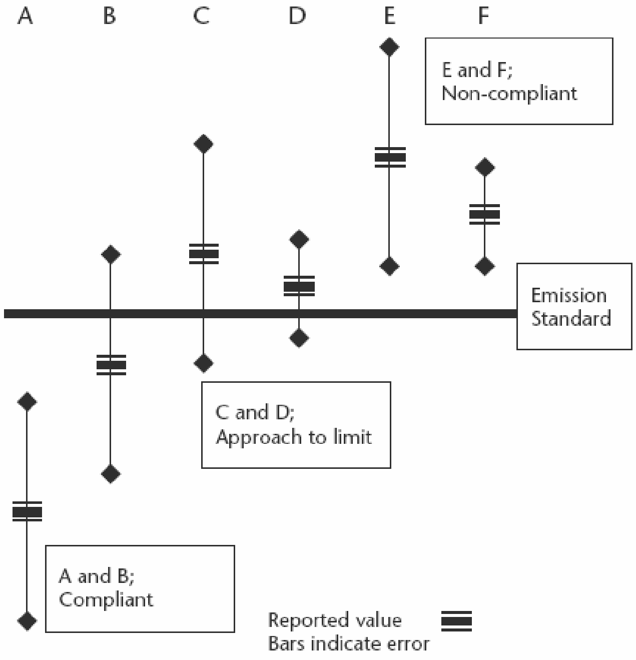


Figure 4.2 Schematic representation of the compliance classification we use in assessing landfill gas engine emissions.

4.6.3 Reporting

The test report must include details of:

- the test methods
- any variations from standard methods
- tabulated data summary
- ambient conditions during sampling

The results must be reported in the form:

Result = X ± U (units)

where:
X = calculated value
U = measurement uncertainty.

The measurement uncertainty should be estimated for the actual monitoring undertaken and, where this is not possible, follow the guidance above. The uncertainty is applied to the result not to the emission limit.

For example; a monitoring exercise is carried out on an engine which has a NOx emission limit of 650 mg/m^3 @ 5% Oxygen. The results of the monitoring give a value of 700 mg/m^3 @ 5% Oxygen with a calculated uncertainty of 25% (10% CEN SRM uncertainty + 15% representative uncertainty). The measurement uncertainty meets the CEN standard and the total calculated uncertainty is less than Table 4.7 so we can assume that the monitoring is representative. The result is therefore expressed as 700 +/- 175 mg/m^3 @ 5% Oxygen. The engine should therefore be reported as 'Approach to Limit'.

4.6.4 Consideration of response

If you assess the data as compliant, they can be routinely reported in accordance with your permit requirements.

If you assess the data as approaching the limit, they should be reported in accordance with your permit requirements, but you should provide information on how they'll reduce uncertainty on subsequent monitoring.

If you assess the data as non-compliant, they should be reported to us immediately in accordance with your permit requirements and this must be investigated. The urgency of this investigation will be determined by the degree of non-compliance and the risk associated with the emission. Following the investigation you will also need to produce an action plan detailing how you intend to rectify the non-compliance.

Your investigation into the non-compliance should identify the cause of the non-compliance and should consider:

- the engine maintenance schedules and engine oil analysis with the aim of identifying potential problems with the operation of engine that may affect the emissions.;
- potential impacts due to inlet gas composition.;
- the condition of internal engine parts such as cylinder heads and seals
- the engine management system and engine set-up
- the management of the related landfill gas extraction system for operational problems.
- re-testing the emissions to demonstrate compliance

As part of the investigation you should also review your current air quality risk assessment using site specific emissions data to determine the process contribution (PC). You should use the PC in conjunction with the background concentration to determine the predicted environmental concentration (PEC) and determine whether the non-compliance has resulted in either a short term or long term breach of air quality standards for protecting human health and ecosystems.

Your action plan should state how you intend to rectify the non-compliance and the timescale. You should include consideration of the following options:

- replacement of plant or elements of plant and elements of the extraction system
- refurbishment of plant and or extraction systems
- revised engine maintenance schedules
- operational changes both in the gas extraction system and engine management systems
- pre-treatment of the inlet gas

The results of the investigation into the non-compliance will determine and your action plan how we score the non-compliance and any subsequent action we may take. The action we take will be consistent with our enforcement and prosecution policies.

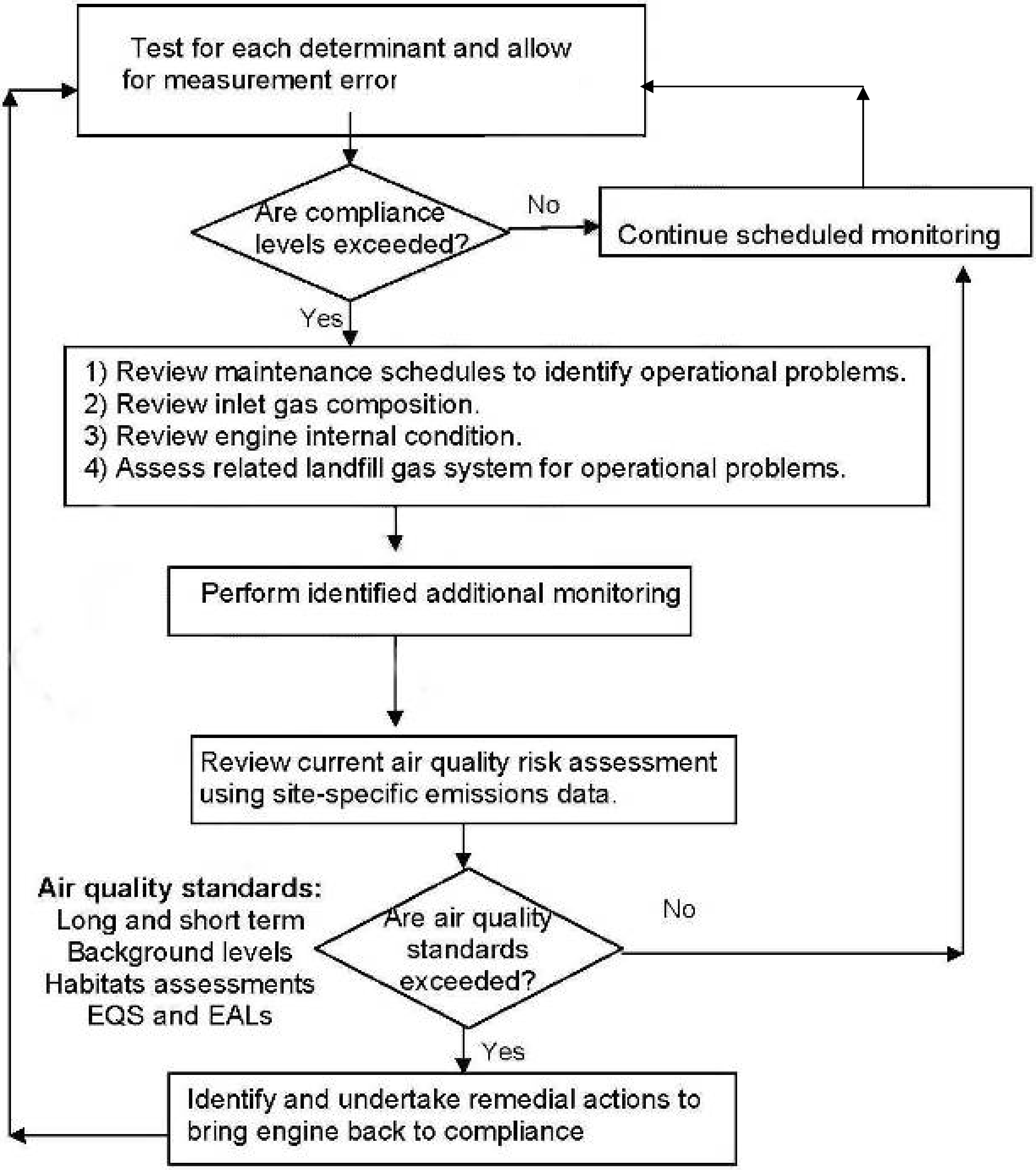


Figure 4.3 Flowchart of the procedure for returning a non-compliant engine to compliance

5. Emission specific methods

Methods for testing stack emissions are continually reviewed and it is not appropriate to refer to specific methods as they may become outdated within the lifetime of this guidance. Details of the specific sampling methods and standards to be applied during emissions testing are contained within our Technical Guidance Notes M1 & M2. Reference must be made to this guidance when carrying out emissions testing.

Appendix A:

Example gas engine sample report format

Report period:…………   to…………………………
Permit number……………………………………...
Operator name…………………………………........
Name of monitoring organisation(s)………….........
Name of analytical organisation(s)………………….
Date issued by operator (dd/mm/yy)………………..

Installation address………………………………
……………………………………………………..
……………………………………………………..
……………………………………………………..

Emission point
Substance
Summary
Permit limit (value limits)
Concentration (value, uncertainty, units)
Mass emission (value, uncertainty, units)
Measurement details
Analytical instrument used
Serial number of instrument used
Accreditation of analytical instrument (MCERTS ref. no.)
Analytical method statement used?
State if sampling compliant with method statement
State if analysis compliant with method statement
Date of sampling (dd/mm/yy)
Time sampling started
Time sampling finished
Limit of detection (LOD) of overall method (value, units)*
Span gas concentration (if applicable)(value, units)
Process conditions
Process status**

Supporting information
Emission point grid reference
Interval between sampling
Date of previous sampling (dd/mm/yy)
Percentage of base load
Ref conditions used (273K abd 101.3kPa) wet/dry, oxygen

* Ideally LOD should be <10 per cent of the permit limit
** Process conditions: N = normal, A = abnormal (e.g. failure of abatement control), T = transitional (e.g. start-up), O = other

Appendix B:

Example gas turbine sample report format

Report period:…………. to………………………… Installation address………………………………
Permit number……………………………………... ……………………………………………………..
Operator name…………………………………......... ……………………………………………………..
Name of monitoring organisation(s)………….......... ……………………………………………………..
Name of analytical organisation(s)………………….
Date issued by operator (dd/mm/yy)………………..

Emission point
Substance
Summary
Permit limit (value limits)
Concentration (value, uncertainty, units) **5%O_2**
Concentration (value, uncertainty, units) **15%O_2**
Mass emission (value, uncertainty, units)
Measurement details
Analytical instrument used
Serial number of instrument used
Accreditation of analytical instrument (MCERTS ref. no.)
Analytical method statement used?
State if sampling compliant with method statement
State if analysis compliant with method statement
Date of sampling (dd/mm/yy)
Time sampling started
Time sampling finished
Limit of detection (LOD) of overall method (value, units)*
Span gas concentration (if applicable)(value, units)
Process conditions
Process status**

Supporting information
Emission point grid reference
Interval between sampling
Date of previous sampling (dd/mm/yy)
Percentage of base load
Ref conditions used (273K abd 101.3kPa) wet/dry, oxygen

* Ideally LOD should be <10 per cent of the permit limit.
** Process conditions: N = normal, A = abnormal (such as, failure of abatement control), T = transitional (start-up), O = other.

Appendix C:

Using electro-chemical cell analysers on landfill gas engines

This method has been developed by the Source Testing Association (STA) and applies to determining nitrogen oxides (NO and NO_2), carbon monoxide (CO), and oxygen (O_2) concentrations emissions from landfill gas-fuelled engines.

Principles of the test method

A gas sample is continuously extracted from a stack and conveyed to a portable analyser for determination of NO, NO_2, CO and O_2 gas concentrations using electrochemical cells. Analyser design specifications, performance specifications, and test procedures are provided to ensure reliable data. The instrument must be subjected to various tests before and after use, or at least once a day if used for longer periods to ensure consistent QA/QC in the results.

Measurement System Performance Specifications

Zero calibration error

Less than or equal to ±3% of the span gas value for NO, NO_2, and CO channels and less than or equal to ±0.3% O_2 for the O_2 channel.

Span calibration error

Less than ±5% of the span gas value for NO, NO_2, and CO channels and less than or equal to ±0.5% O_2 for the O_2 channel.

Interference response

The CO and NO interference responses must be less than or equal to ±5% of the average stack concentration for the tests, checked annually by analyser supplier.

Linearity

For the zero, mid-level, and span gases; the absolute value of the difference between the gas value and the analyser response shall not be greater than 2.5% of the span gas concentration for NO, CO and O_2 cells and not greater than 3.0% of the span gas for NO_2 cells, checked annually by the analyser supplier.

Stability check response

The analyser responses to CO, NO, and NO_2 span gases shall not vary more than 2.0% of span gas value over a 30-minute period or more than 1.0% of the span gas value over a 15- minute period, checked annually by the analyser supplier.

Range and sensitivity

Analytical range

The analytical range for each gas component is determined by the electrochemical cell design. A portion of the analytical range is selected by choosing a span gas concentration near the flue gas concentrations

CO and NO span gases

Span gas concentration used must not be greater than twice the concentration the expected average stack gas reading for each.

NO_2 span gas

Choose a span gas not greater than the ppm concentration value of the NO span gas. The operator should be aware that NO_2 cells are generally designed to measure much lower concentrations than NO cells and the span gas should be chosen accordingly. If concentration results exceeds 125 percent of the span gas at any time during the test(s) then that test is invalid.

O_2 span gas

Dry ambient air (20.9% O_2) may be used and is advisable to have an additional gas between 5% and 10%.

Sensitivity

The minimum detectable limit depends on the nominal range of the electrochemical cell, calibration drift, and signal-to-noise ratio of the measurement system. For a well designed system, the minimum detectable limit should be less than 2% of the nominal range.

Analyser and accessories required on site

Analyser (measurement system)

Use any measurement system that meets the performance and design specifications above. The sampling system shall maintain the gas sample at a temperature above the dew point up to the moisture removal system. The sample conditioning system shall be designed so that there are no entrained water droplets in the gas sample when it contacts the electrochemical cells. A schematic of the measurement system is shown in Figure C.1. The essential components of the measurement system are described below:

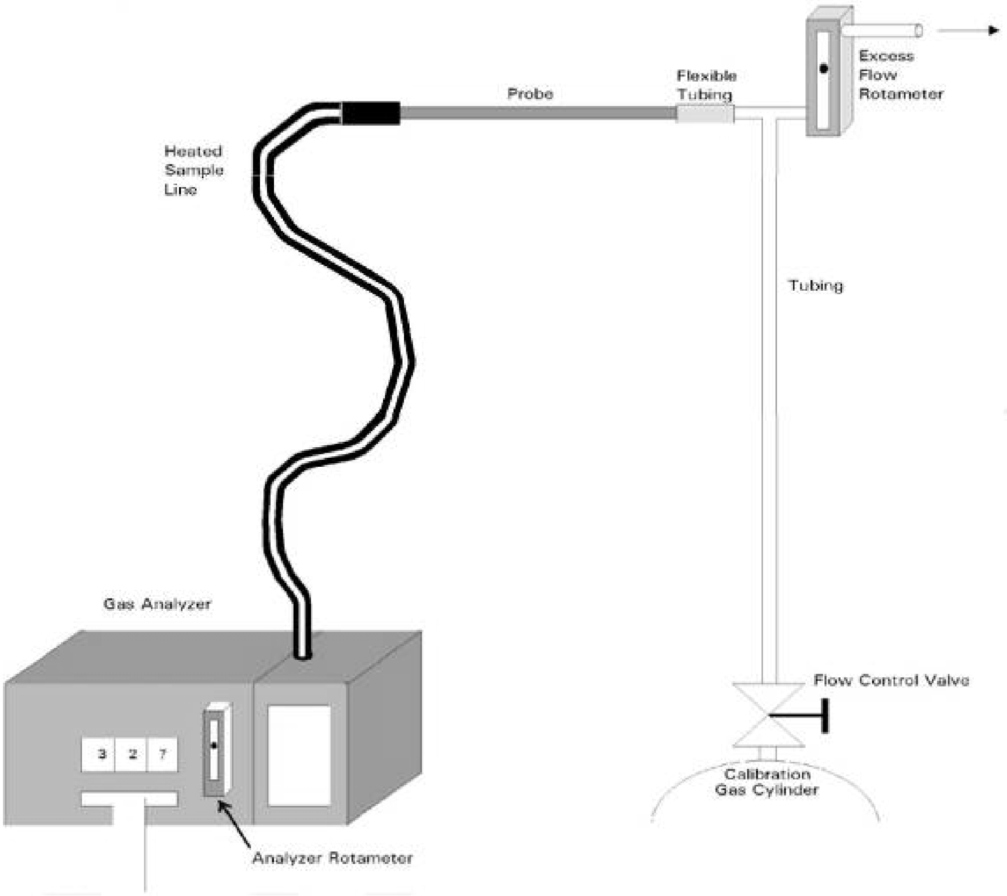
Sample probe

Glass, stainless steel, or other non-reactive material, of sufficient length to traverse the sample points. Some systems have dedicated probes for high temperature application, consult with manufactures. If necessary to prevent condensation, the sampling probe shall be heated.

Sample line

The sample line should be designed to prevent gas coming into contact with condensate (sufficient to prevent condensation) non-reactive tubing, to transport the sample gas to the moisture removal system. If there is no dedicated system then heated sample line should be used. Consult with manufacturer regarding suitability.

Figure C.1 Electrochemical cell calibration set up.



Calibration assembly
A tee fitting to attach to the probe tip for introducing calibration gases at ambient pressure during the calibration error checks. The vented end of the tee has a flow indicator to ensure sufficient calibration gas flow.

Moisture removal system
A chilled condenser, or similar device (e.g., permeation dryer), is required to remove condensate continuously from the sample gas while maintaining minimal contact between the condensate and the sample gas.

Particulate filter
Filters at the probe or the inlet or outlet of the moisture removal system and inlet of the analyser may be required to prevent accumulation of particulate material in the measurement system and extend the useful life of the components. All filters shall be fabricated of materials that are non-reactive to the gas being sampled.

Sample pump
A leak-free pump, to pull the sample gas through the system at a flow rate sufficient to minimize the response time of the measurement system is required. The pump may be constructed of any material that is non-reactive to the gas being sampled. This is normally integrated within the analyser.

Sample flow rate control
A sample flow rate control valve and flow meter, or equivalent, to maintain a constant sampling rate within 10% during sampling and calibration error checks. The components shall be fabricated of materials that are non-reactive to the gas being sampled. This is normally integral within the analyser.

Gas analyser
The instrument containing electrochemical cells to determine the NO, NO_2, CO and O_2 concentrations in the sample gas stream and, if necessary, to correct for interference effects. The analyser shall meet the applicable performance specifications above.

Data recorder
A printer, generally integral with the analyser, strip chart recorder, computer, or digital recorder, for recording measurement data is required.

External interference gas scrubber
Used by some analysers to remove interfering compounds upstream of a CO electrochemical cell. The scrubbing agent should be visible and should have a means of determining when the agent is exhausted (i.e. colour indication).

NO cell temperature Indicator
A thermocouple, thermistor, or other device must be used to monitor the temperature of the NO electrochemical cell. The temperature may be monitored at the surface or within the cell.

Calibration gases
The calibration gases for the gas analyser shall be: CO in nitrogen or CO in nitrogen and O_2; NO in nitrogen; NO_2 in air or nitrogen; and O_2 in nitrogen. The mixtures can be combined e.g. O_2 and CO with balance nitrogen.

Span gas(es) with a concentration less than 0.25 per cent for each component may be used as Zero gas(es.) Ambient air may be used as a zero gas in a well ventilated area except for zeroing O_2.

Measurement system performance check procedures

Perform the following procedures before measurement of emissions. These tests are carried out in the office/laboratory.

Warm up period

Assemble the sampling system and allow the analyser and sample interface to warm up in line with the manufactures recommendation and adjust to ambient temperature.

Pre-test and post-test calibration error check

Conduct the calibration error check in the office/laboratory prior to taking the analyser on site. For analysers that use an external interference gas scrubber tube, inspect the condition of the scrubbing agent and ensure that it will not be exhausted during the on-site tests. Inject the zero and span calibration gases at the probe tip using the calibration assembly. Ensure that the calibration gases flow through all parts of the sample interface (including any exhaust lines). During this check, make no adjustments to the system except those necessary to achieve the correct calibration gas flow rate at the analyser. Set the analyser flow rate to the value recommended by the analyser manufacturer. Allow each reading to stabilize before recording the result on a form similar to Appendix 4. The time allowed for the span gas to stabilize shall be no less than the stability time noted during the stability check. After achieving a stable response, disconnect the gas and briefly purge with ambient air. Determine the NO and CO response times by observing the time required to respond to 95% of a step change in the analyser response for both the zero and span gases. Note the longer of the two times as the response time. For NO_2 span gas record the time required to respond to 90% of a step change. Calibrate all electrochemical cells in the analyser if the analyser uses an internal calculation method to compensate for interferences. If the zero and span calibration error test results are not within the specification given above, take corrective action and repeat the calibration error check until acceptable performance is achieved. The above to be repeated after on-site test have been completed.

Emission test procedure

Warm up period

Assemble the sampling system and allow the analyser and sample interface to warm up in line with the manufactures recommendation and adjust to ambient temperature at the location where the stack measurements will take place.

Pre-test calibration error check

Conduct the calibration error check at the sampling location (near the sampling port) just prior to the start of the tests on the O2 range using ambient air in line with the manufacturer's recommendations.

Selection of sampling site and sampling points

Select a sampling site located at least five stack diameters downstream of any turbocharger exhaust, crossover junction, or recirculation take-offs and upstream of any dilution air inlet. Locate the sampling site no closer than one meter or three stack diameters (whichever is less) upstream of the gas discharge to the atmosphere. Use a sampling point located at the middle of the stack diameter.

Sample collection

Position the sampling probe. Begin sampling at the same rate used during the calibration error check. Maintain constant rate sampling during the entire test run. The sample period must be for a minimum of 15 minutes or at the time used on previous tests. If recording emission data manually, record concentration values at least once each minute. If a computer or the analyser record data automatically, the concentration data must be recorded either (1) at least once each minute, or (2) as a block average for the test run using values sampled at least once each minute. Do not break any seals in the sample handling system until after the post test calibration error test (this includes opening the moisture removal system to drain condensate). The temperature of the electrochemical cells shall be monitored regularly (at least once every 5 minutes) during the sample collection period. At no time shall the analyser be used outside the manufacturer's recommended operating temperature range.

At the end of the test run remove sample probe from the sampling point and purge the measuring system with fresh air for a minimum of 5 minutes to clear the system of sample gases.

Post test calibration error check

Immediately after the test run or set of test runs conduct span and zero calibration error checks using the described procedure. Conduct the calibration error check at the sampling location. Make no changes to the sampling system or analyser calibration until all of the calibration error test results have been recorded. If the zero or span calibration error exceeds the specifications in this Appendix then all test data collected since the previous calibration error check are invalid. If the sampling system is disassembled or the analyser calibration is adjusted, repeat the calibration error check before conducting the next test or test run.

Interference verification

The operator shall review the results of the post test calibrations and compare them to the results of the most recent interference test. Use the post test calibration results and average emission concentrations for the test to calculate interference responses using the procedure specified by the manufacturer. If an interference response exceeds 5%, all emission test results since the last successful interference test for that compound are invalid.

Re-zero

At least once every three hours or each time the analyser sampling location changes, recalibrate the analyser at the zero level according to the manufacturer's instructions and conduct a pre-test calibration error test before resuming sampling.

Data recording

Tests data shall be recorder on a form similar to Appendix A. All other automatic recordings shall be saved for future reference.

Periodic checks

Annually

The instrument shall be returned to the manufacturer for annual service and detailed checks which will include linearity and stability as a minimum. The manufacture to provide a report of work carried out with test results.

Checks when compliance tests take place

When external contractors undertake compliance assessment monitoring the electro-chemical cell analyser shall be checked by running in parallel with the operator's analysers.

Definitions of terms

Analyser (measurement system)

Use any measurement system that meets the performance and design specifications above. The sampling system shall maintain the gas sample at a temperature above the dew point up to the moisture removal system. The sample conditioning system shall be designed so that there are no entrained water droplets in the gas sample when it contacts the electrochemical cells.

Sample probe

Glass, stainless steel, or other non-reactive material, of sufficient length to traverse the sample points. Some systems have dedicated probes for high temperature application, consult with manufactures. If necessary to prevent condensation, the sampling probe shall be heated.

Sample line

The sample line should be designed to prevent gas coming into contact with condensate (sufficient to prevent condensation) non-reactive tubing, to transport the sample gas to the moisture removal system. If there is no dedicated system then heated sample line should be used. Consult with manufacturer regarding suitability.

Calibration assembly

A tee fitting to attach to the probe tip for introducing calibration gases at ambient pressure during the calibration error checks. The vented end of the tee has a flow indicator to ensure sufficient calibration gas flow.

Moisture removal system

A chilled condenser, or similar device (e.g., permeation dryer), is required to remove condensate continuously from the sample gas while maintaining minimal contact between the condensate and the sample gas.

Particulate filter

Filters at the probe or the inlet or outlet of the moisture removal system and inlet of the analyser may be required to prevent accumulation of particulate material in the measurement system and extend the useful life of the components. All filters shall be fabricated of materials that are non-reactive to the gas being sampled.

Sample pump

A leak-free pump, to pull the sample gas through the system at a flow rate sufficient to minimize the response time of the measurement system is required. The pump may be constructed of any material that is non-reactive to the gas being sampled. This is normally integrated within the analyser.

Sample flow rate control

A sample flow rate control valve and flow meter, or equivalent, to maintain a constant sampling rate within 10% during sampling and calibration error checks. The components shall be fabricated of materials that are non-reactive to the gas being sampled. This is normally integral within the analyser.

Gas analyser

The instrument containing electrochemical cells to determine the NO, NO_2, CO and O_2 concentrations in the sample gas stream and, if necessary, to correct for interference effects. The analyser shall meet the applicable performance specifications above.

Data recorder

A printer, generally integral with the analyser, strip chart recorder, computer, or digital recorder, for recording measurement data is required.

External interference gas scrubber

Used by some analysers to remove interfering compounds upstream of a CO electrochemical cell. The scrubbing agent should be visible and should have a means of determining when the agent is exhausted (i.e. colour indication).

NO cell temperature Indicator

A thermocouple, thermistor, or other device must be used to monitor the temperature of the NO electrochemical cell. The temperature may be monitored at the surface or within the cell.

Calibration gases

The calibration gases for the gas analyser shall be CO in nitrogen or CO in nitrogen and O_2, NO in nitrogen, NO_2 in air or nitrogen, and O_2 in nitrogen. The mixtures can be combined e.g. O_2 and CO with balance nitrogen.

Span gases

Used for checking the span of the instrument and the calibration error.

Zero gas

Concentrations of less than 0.25 per cent of the span gas for each component. Ambient air may be used in a well ventilated area except for O_2.

Appendix D:

Calibration check sheet

Operator name ____________________________
Date ____________________________
Analyst ____________________________
Analyser manufacturer/model no. ____________________________
Analyser serial number ____________________________

Pre-test calibration error check result

Channel	Zero gas conc.	Zero response	Zero error (%)	Span gas conc.	Span response	Span error (%)
NO						
NO_2						
CO						
O_2						

Post test calibration error check results

Channel	Zero gas conc.	Zero response	Zero error (%)	Span gas conc.	Span response	Span error (%)
NO						
NO_2						
CO						
O_2						

Signed…………………………………..………..

Glossary and acronyms

Absorption
A process in which a gas is taken up by a liquid or a solid.

Adsorption
A process in which a layer of atoms or molecules of one substance forms on the surface of a solid or liquid.

Base load power generation
Continuous operation at maximum output.

Biodegradable waste
Any waste (e.g. food, garden waste and paper) capable of undergoing decomposition by micro-organisms under anaerobic or aerobic conditions.

Biogas
A methane-based fuel that is produced through the bio-digestion of organic material.

BSI
British Standards Institution

CEMS
Continuous emission monitoring system

CEN
Comité Europeén de Normalisation

Chemiluminescence
The emission of light during a chemical reaction.

Continuous Monitoring
The use of automated inline analysers that provide frequent, though not uninterrupted, data.

Covalent
A covalent bond is a chemical bond formed between atoms by the sharing of electrons.

Diesel engine
Any compression-ignited internal combustion engine.

DIN
Deutsches Institute für Normung

DTI
Department of Trade and Industry

Dual-fuel engine
Any internal combustion engine that is designed to burn a liquid and a gaseous fuel mixture during a single operating cycle.

Duct
An enclosed structure through which gases travel

Electromotive force
Electromotive force (also known as voltage) is a quantitative expression of the potential difference in charge between two points in an electrical field. The greater the voltage, the greater the flow of electrical current (i.e. the quantity of charge carriers that pass a fixed point per unit of time) through a conducting or semi-conducting medium for a given resistance to the flow.

ELV
Emission limit value

FID
Flame ionisation detector

Flue
See duct

FPD
Flame photometric detection. Detection unit in a gas chromatograph that specifically measures compounds containing phosphorus and sulphur.

FTIR
Fourier transform infra-red spectrometry

GC
Gas chromatography. The process to enable the components of a sample gas to be separated by passing the gas through a column with a high surface to volume ratio. The separated components are measured using an appropriate detector.

GC/MS
Gas chromatography/mass spectrometry

Homogeneous
A homogeneous mixture is uniformly and complete mixed.

IC
Internal combustion

ICCR
Industrial Combustion Co-ordinated Rulemaking Federal Advisory Committee of the USEPA

Internal combustion (IC) engine, stationary
Any reciprocating, piston driven IC engine that is operated or intended to be operated at one specific location for more than 12 months or that is attached to a foundation at the location.

Ionise
To convert wholly or partly into ions.

IR
Infra-red

ISE
Ion-selective electrode

ISO
International Organisation for Standardization

Isokinetic sampling
Isokinetic sampling is achieved when the gas enters the sampling nozzle at exactly the same velocity and direction as the gas travelling in the exhaust.

Landfill gas
All gases generated from the landfilled waste.

Lean-burn engine
Any spark ignited internal combustion engine that is operated with an exhaust stream oxygen concentration of ≥4 per cent by volume prior to any exhaust stream control device.

MCERTS
Monitoring Certification Scheme

MS
Mass spectrometry

NDIR
Non-dispersive infra-red spectrometry

NFFO
Non-Fossil Fuel Obligation

NMVOCs
Non-methane volatile organic compounds

PAHs
Polycyclic aromatic hydrocarbons

PCDD
Polychlorinated dibenzo-p-dioxin

PCDF
Polychlorinated dibenzo furan

QA
Quality assurance

QC
Quality control

REC
Regional electricity company

Rich-burn engine
Any spark ignited internal combustion engine that is operated with an exhaust stream oxygen concentration of < 4 per cent by volume prior to any exhaust stream control device.

ROC
Renewables Obligation Certificate

RPI
Retail Price Index

Sampling location
A suitable position on the site where representative samples can be obtained.

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 in the wall of the stack, duct or flue through which access to the emission gas can be gained.

Sampling position
See Sampling location.

Sampling section
See Sampling plane.

Spectral line
A particular wavelength of light emitted or absorbed by an atom, ion or molecule.

STA
Source Testing Association

Stack
A structure (i.e. chimney) through which emissions are released to atmosphere.

Stoichiometric
The exact proportions in which substances react. For combustion, a theoretical minimum amount of air or oxygen required to consume the fuel completely.

UKAS
United Kingdom Accreditation Service

Ultraviolet (UV)
A form of electromagnetic radiation, shorter in wavelength than visible light.

USEPA
United States Environmental Protection Agency

VDI
Verein Deutscher Ingenieure (Dutch national standards body)

VOC
Volatile organic compound

XAD
Trade name for polystyrene adsorbent resin beads

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