

1. Home (<https://www.gov.uk/>)
2. Environmental permits (<https://www.gov.uk/topic/environmental-management/environmental-permits>)

Guidance

# Monitoring stack emissions: technical guidance for selecting a monitoring approach

Formerly part of M2, guidance to help organisations choose a monitoring approach for stack emissions to air that meets Environment Agency and MCERTS requirements.

Published 18 December 2019

From:

Environment Agency (<https://www.gov.uk/government/organisations/environment-agency>)

Applies to:

Wales and England

## Contents

- How this guidance relates to MCERTS
- The different approaches to monitoring stack emissions
- The main elements of successful monitoring
- Isokinetic sampling for particulates
- Sample conditioning
- Access, facilities and services
- Reporting results
- Monitoring strategy
- Targeting the substance to measure
- Number and duration of samples
- Field blanks for manual sampling
- Limit of detection of the method
- Instrument certified ranges
- Instrument zero and span operations
- Choice of monitoring method
- Collecting and reporting data and process conditions
- Measurement uncertainty
- Non-compliant sample locations
- Calibration of CEMS
- Quality assurance of predictive emissions monitoring systems

- Reporting
- Safety

This technical guidance note is for monitoring organisations, industry and others interested in monitoring stack emissions to air. It is also a technical reference for the Environment Agency's Monitoring Certification Scheme (MCERTS) and Operator Monitoring Assessment scheme. This guidance was formerly part of the M2 guidance document.

The main reasons for carrying out stack emission monitoring are to:

- comply with environmental legislation
- collect data for emissions inventory compilation
- calibrate continuous emission monitoring systems (CEMS)
- collect data for environmental impact assessments
- collect data to assess process efficiency and process control
- assess the performance of a pollution-control device (abatement system)

This document describes our overall approach to stack emission monitoring. It focuses on:

- the role of MCERTS
- different approaches to stack emission monitoring
- sampling strategy
- the hierarchy of different methods

To support this guidance, we have produced guidance on monitoring techniques and standards for:

- CEMS and automated batch samplers (<https://www.gov.uk/guidance/monitoring-stack-emissions-techniques-and-standards-for-CEMS-and-automated-batch-samplers>)
- periodic monitoring (<https://www.gov.uk/guidance/monitoring-stack-emissions-techniques-and-standards-for-periodic-monitoring>)

The guidance on monitoring techniques and standards is classified by substance and meets our monitoring requirements under the environmental permitting regulations (EPR).

Applications for environmental permits must include proposals for monitoring emissions. Permits include conditions setting out suitable emission monitoring requirements. These will specify the:

- measurement methodology
- monitoring frequency
- reporting procedures

Wherever possible, you should monitor emissions using standards from recognised standards making organisations.

## **How this guidance relates to MCERTS**

**MCERTS** is for instruments, monitoring and analyses. The scheme is built on proven international standards. It provides industries with a framework for choosing monitoring systems and services that meet our performance specifications. **MCERTS** brings together relevant standards into a scheme that manufacturers, operators, regulators and test houses can easily access.

The main reference documents that underpin **MCERTS** for stack emission monitoring are:

- this guidance document which covers choosing the correct monitoring approach
- monitoring techniques and standards for **CEMS** and automated batch samplers (<https://www.gov.uk/guidance/monitoring-stack-emissions-techniques-and-standards-for-CEMS-and-automated-batch-samplers>)
- monitoring techniques and standards for periodic monitoring (<https://www.gov.uk/guidance/monitoring-stack-emissions-techniques-and-standards-for-periodic-monitoring>)
- M1 sampling requirements for stack emission monitoring (<https://www.gov.uk/government/publications/m1-sampling-requirements-for-stack-emission-monitoring>) which covers the sampling and safety requirements

International standard EN **ISO/IEC 17025** covers the competence of testing laboratories. It describes the general requirements laboratories have to meet to demonstrate that they:

- operate a quality system
- are technically competent
- can generate technically valid results

To comply with **MCERTS** for stack emission monitoring, organisations need to meet the requirements of EN **ISO/IEC 17025**. They must also:

- use **MCERTS** certified personnel
- use Agency Method Implementation Documents
- carry out risk assessments
- use site-specific protocols (measurement plans)
- report results in a standard format
- get stack emissions monitoring samples analysed by laboratories accredited to the **MCERTS** performance standard for testing samples from stack emissions monitoring

## **The different approaches to monitoring stack emissions**

There are 2 types of stack emissions monitoring:

### **Periodic measurements**

This is where you carry out measurements at periodic intervals, such as once every 3 months. You withdraw the sample from the stack and either analyse it off-site or measure it on-site.

You may use:

- a manual technique – where you extract a sample on-site and then analyse it in a laboratory

- an instrumental or automatic technique – where you extract a sample and analyse it on-site using a transportable automated measuring system

You may obtain samples every 30 minutes to several hours.

## **CEMS**

This is where you carry out automatic measurements continuously. You may carry out measurements in the stack (in situ) or use extractive sampling with an instrument permanently located at or near the stack.

### **The main elements of successful monitoring**

Whichever monitoring approach you choose, you must follow this fundamental principle of sampling: the small amount of material you collect must be representative of the overall character of the material.

The number, and locations, of samples you need to make up a representative sample depends on how homogeneous the bulk material (the stack gas) is. If the stack gas is homogeneous, you may only need a few samples. If it is not homogeneous, you will need many more samples.

Our requirements for representative sampling are covered in M1 sampling requirements for stack emission monitoring (<https://www.gov.uk/government/publications/m1-sampling-requirements-for-stack-emission-monitoring>). Because sampling uncertainty is often much greater than analytical uncertainty, it is crucial that you follow this guidance on sampling.

### **Isokinetic sampling for particulates**

Due to the wide range of particle sizes that are normally present in process emission streams, you must sample isokinetically to make sure you obtain a representative sample of the particulate emission.

To perform isokinetic sampling, you need to calculate the required sampling flow rate. This is to make sure that the velocity of the gas entering the nozzle is the same as the velocity of the stack gas at the sampling plane. This takes into account the velocity of the gas in the stack at the sampling point and the effective diameter of the sampling nozzle.

Sampling flow rate = area of nozzle × velocity of gas entering nozzle.

By comparing the velocity of the gas at the nozzle with the velocity of the stack gas at the sampling plane, you can determine the isokinetic ratio.

Isokinetic ratio (%) = (velocity at the nozzle ÷ velocity of stack gas) × 100.

You can also check for isokinetic sampling compliance during monitoring by comparing the required sampling flow rate to the actual sampling flow rate.

Isokinetic ratio (%) = (actual sampling flow rate ÷ required sampling flow rate) × 100.

If the mean actual isokinetic ratio during the sampling at the sampling plane differs by more than -5 to +15% the measurement is not valid. This is stated in Standard BS EN 13284-1 for determining the low range mass concentration of dust.

If the sampling velocity is less than the isokinetic ratio (usually expressed as a percentage), the actual volume sampled will be less than it should be.

At first sight, it would appear that you will underestimate the emission. However, because the sampling rate is too low, there is a divergence in flow around the sampling inlet. Small particles are able to follow the flow and a percentage of them will not be sampled. Larger particles are not able to follow the flow because of their greater inertia so more of them will enter the sampler.

So, a sub isokinetic sampling ratio will lead to a bias in the sampled particle-size distribution towards the larger particles. This could lead to you overestimating the particulate concentration, depending on the original size distribution.

Sampling at a rate higher than the isokinetic ratio will lead to a bias in the sampled particle-size distribution towards the smaller particles. This could lead to you underestimating the emission rate, depending on the original size distribution.

## **Sample conditioning**

With the exception of in situ CEMS, the collected sample is usually conditioned in some way before it is analysed. It is important that any conditioning you carry out to make the gas compatible with the analysis method does not alter the substance being monitored.

This conditioning may occur:

- at the probe
- during transport to the analysis stage
- just before analysis

Some examples of sample conditioning during the extractive monitoring of gases are by using a:

- particulate filter in the sampling probe to prevent particulate matter depositing further downstream or carrying over to the analysis stage (or both)
- heated sample line to prevent condensation during transport from the probe to the analysis stage
- system to remove moisture from the sample using, for example, a cooling system or permeation drier
- dynamic system to dilute the sample by a known factor to below its dew point

## **Access, facilities and services**

The access, facilities and services you need for sampling will vary depending on the approach, technique or type of equipment. However, all require:

- a safe way of accessing the sampling position
- a safe place of work at the sampling position
- a way of getting sampling equipment into the stack
- enough space for the equipment and personnel
- essential services, for example, electricity, lighting and water

See M1 sampling requirements for stack emission monitoring

(<https://www.gov.uk/government/publications/m1-sampling-requirements-for-stack-emission-monitoring>) for more information. These factors may limit the approach, technique, method and equipment you can use.

## Reporting results

When reporting results for regulatory purposes, you must meet the conditions in your permit. For periodic monitoring, your reports should meet the requirements in the MCERTS performance standard for organisations carrying out manual stack emission monitoring (<https://www.gov.uk/government/publications/mcerts-performance-standard-for-organisations-monitoring-manual-stack-emissions>).

## Calculating concentration and mass emissions

To comply with your permit you must report results as concentrations or mass emission rates.

To calculate a concentration, you divide the mass of the substance collected during sampling by the volume of stack gas sampled:

Concentration = mass of substance ÷ sample volume.

To convert a concentration to a mass emission, you need to know the volume flow rate of gas discharged from the stack:

- stack gas volume flow rate ( $\text{m}^3/\text{s}$ ) = velocity of stack gas ( $\text{m}/\text{s}$ ) × cross-sectional area of stack ( $\text{m}^2$ )
- mass emission rate ( $\text{mg}/\text{s}$ ) = concentration measured ( $\text{mg}/\text{m}^3$ ) × stack gas volume flow rate ( $\text{m}^3/\text{s}$ )
- mass emissions ( $\text{mg}$ ) = mass emission rate ( $\text{mg}/\text{s}$ ) × time period (s)

The volume flow rate and concentration must be at the same reference conditions (see Correcting results to standard conditions). You do not subtract the measurement uncertainties from mass emission results.

Normally, when you are using continuous monitoring, you calculate the half-hourly (or hourly) mass emission from the half-hourly (or hourly) average concentration and the average stack gas volume flow rate. The concentration and flow rate should be at the same reference conditions. You can sum up values over longer periods, such as monthly or annually. You should use larger mass units, such as kg, tonnes or ktonnes for these longer time periods.

For combustion plants that do not have continuous monitoring (typically < 100 MW), you can calculate the annual total stack gas volume from the annual fuel consumption (see Annex E of EN ISO 16911-1 – velocity and volume flow rate).

You determine the annual mass emission from the annual average measured pollutant concentration, multiplied by the annual stack gas volume.

It is good practice to verify the calculation by measuring the stack gas volume flow rate using either a velocity or tracer injection method, according to EN ISO 16911-1.

## Converting results from parts per million to $\text{mg}/\text{m}^3$

You express monitoring results in gravimetric units ( $\text{mg}/\text{m}^3$ ). Most calibration gases have concentration values given in gravimetric units of parts per million (ppm), which are independent from temperature and pressure.

You may need to convert results obtained as ppm to  $\text{mg}/\text{m}^3$  to meet the conditions of permits or authorisations. To convert ppm to  $\text{mg}/\text{m}^3$ , you need to use the following equation.

Concentration ( $\text{mg}/\text{m}^3$ ) = concn. (ppm)  $\times$  molecular weight (g)  $\div$  molar volume (l).

The molar volume is the volume occupied by one-gram mole of a gas at a specific temperature and pressure. Concentrations are usually reported at this temperature and pressure – 273K and 101.3 kPa.

Under these conditions, the molar volume for an ideal gas is equal to 22.40 litres.

## Correcting results to standard conditions

You must report concentration measurements to a standard set of conditions. This is so comparisons can be made with emission:

- limit values (ELVs)
- concentrations measured at different times on the same site
- concentrations at different sites

Only concentration measurements expressed as mass per unit volume, for example  $\text{mg}/\text{m}^3$ , are affected by temperature pressure, moisture and oxygen concentration.

Concentrations expressed as volume per unit volume, for example ppm, are unaffected by temperature and pressure.

Mass emissions results, for example kg/h, are unaffected by temperature, pressure, oxygen and moisture levels.

Your permit or authorisation will specify the reference conditions that apply to you. It will specify reference conditions for temperature and pressure, and may also set them for moisture and oxygen content.

You usually report concentration measurements to 273 K and 101.3 kPa. Since the measured concentrations will not be at these conditions, you will need to apply correction factors  $F_t$  and  $F_p$  for temperature and pressure respectively.

To convert the concentration as measured at a temperature of T K, to the concentration at 273 K, multiply by  $F_t$  where:  $F_t = T \div 273$ .

To convert the concentration as measured at a pressure of P kPa, to the concentration at 101.3 kPa, multiply by  $F_p$  where:  $F_p = 101.3 \div P$ .

For concentration measurements, P will be the pressure at the point where you measure the sample volume.

The level of water vapour and oxygen affects the as-measured concentration of a substance because they add to the volume that the mass of pollutant occupies. This is particularly relevant for processes involving combustion, where oxygen is consumed and water vapour is produced during the combustion process.

The oxygen level can cause significant changes in measured concentrations.

Many permits therefore require you to express the concentration results at a standard oxygen reference level. The oxygen reference level will be set by the competent authority at a level that is appropriate for your process. It will be based on the typical oxygen level of the process when it is running with normal conditions and fuel type. Different oxygen reference values are used for different fuels, for example:

- 3% for gas or liquid fuels
- 6% for solid fuels
- 11% for most incineration processes
- 15% for gas turbines

However, some processes may be designed to run in an oxygen enriched atmosphere. Under these circumstances you can standardise the results of the measured concentrations at an oxygen content laid down by the competent authority. This will reflect the special circumstances of the individual case.

Moisture has a smaller, but still significant, effect and the correction is usually to zero moisture (dry). You must measure the moisture content of the exhaust gas, H<sub>2</sub>O%, using an appropriate technique and method.

Emissions of stack gases are often expressed on a dry gas basis so that a variation in the moisture of stack gas does not affect the assessment of the emissions.

To convert a concentration from wet gas to dry gas, use the following:

Dry gas concentration = wet gas concentration × 100 ÷ (100 – H<sub>2</sub>O%).

To convert a concentration as measured, to a concentration at reference oxygen level, multiply the concentration by Fo. The correction factor for oxygen, given by  $F_o = (21 - O_2\% \text{ reference}) / (21 - O_2\% \text{ measured})$ .

Your permit will specify the reference oxygen level.

## Monitoring strategy

You must have a monitoring strategy. The main elements of a monitoring strategy cover:

- safety (see M1 sampling requirements for stack emission monitoring (<https://www.gov.uk/government/publications/m1-sampling-requirements-for-stack-emission-monitoring>))
- which substance to sample
- when to sample, for how long and how many samples to take
- which technique, method and equipment to use
- where to sample from (see M1 sampling requirements for stack emission monitoring (<https://www.gov.uk/government/publications/m1-sampling-requirements-for-stack-emission-monitoring>))
- collecting and reporting data
- quality assurance and control

It is essential that you have an effective quality assurance (QA) or quality control (QC) system to make sure you get high quality results and eliminate invalid data.

## Site-specific protocols

For CEMS the monitoring strategy is likely to be in place long term. In contrast, organisations carrying out periodic monitoring should review their monitoring strategies every time they carry out a monitoring campaign.

You must document the monitoring strategy for a periodic monitoring campaign in a site-specific protocol (SSP).

The MCERTS performance standard for organisations carrying out stack emission monitoring (<https://www.gov.uk/government/publications/mcerts-performance-standard-for-organisations-monitoring-manual-stack-emissions>) has the requirements for SSPs.

Where you propose to monitor using CEMS, you should summarise factors such as calibration and maintenance arrangements in a documented protocol.

## Targeting the substance to measure

For regulatory monitoring the substances will be those specified in your permit. However, even when the substance has been specified, you may still need to consider what precise form of the substance you should measure.

## Different phases

You sample particulates by extracting flue gas from a stack and collecting the material on a filter. When sampling for a gas, you extract the sample and collect the required substance into a solution. Or you absorb it onto a solid adsorbent, for example, activated carbon for volatile organic components.

Some substances exist simultaneously in both gaseous and particulate phases. Examples of this are organic pollutants such as dioxins and furans, and inorganic pollutants such as mercury.

The monitoring method you use must be able to sample the selected phase or both phases, as appropriate. For example, mercury is mainly present in gaseous form, but can also be found in a particulate phase. So a manual method to determine the concentration of total mercury requires a filter for the particulate phase and a series of absorbers for the gas phase.

## Total or speciated measurements

For certain pollutants it is common to express the concentration as the sum total of the individual species present, for example, total heavy metals.

Some members of a group of pollutants may be especially important and may require specific determination, such as cadmium and thallium.

Similarly you can sample for a particular physical fraction of particulate matter, such as particles less than 10µm in diameter (known as PM10).

## Number and duration of samples

CEMS, supported by the appropriate checking and calibration (QA or QC) provide increased confidence for regulatory purposes and process control.

However, periodic monitoring alone may be acceptable depending on the process or installation. For example, periodic monitoring is normally appropriate when sampling a batch process.

You then need to make a further choice between carrying out:

- periodic monitoring using automated instruments giving a real-time readout
- manual monitoring giving a result averaged over the sampling period

Generally, the more variable the emissions, the more frequently you will need to carry out periodic monitoring. You should carry out sampling using a continuous system (where available) if emissions levels vary so frequently and significantly that intermittent sampling would be:

- unrepresentative
- required too frequently to be practicable

## **Averaging periods and duration of sampling**

Choosing a suitable averaging period is strongly influenced by:

- the expected short-term variability in emission levels (concentrations or mass emissions or both)
- whether such peaks are important

You must choose an averaging period that is consistent with the release limit against which you will compare your result, and as specified in your permit.

A particular averaging period may limit your choice of measuring techniques and vice-versa. Some methods may be capable of operating only within a finite range of sampling averaging times. The points you need to consider will differ between automated instrumental techniques and manual techniques.

Direct-reading analysers can provide large quantities of data with a fine time resolution. Selecting an appropriate averaging time is limited (in principle) only by the instrument's response time. However, you can expect a minimum duration of at least half an hour or more per measurement. The minimum averaging time for a CEMS to obtain an independent result is equal to at least 4 response times.

In contrast, the averaging time for a manual technique is often constrained by needing a sample run of an appropriate duration (often half an hour or more).

This is because manual techniques have an associated analytical end-method stage (for example, weighing of particulate samples). So, you must sample a sufficient mass of pollutant to achieve an adequate limit of detection.

The mass you sample depends on the pollutant flux into the sampler. The determining factor therefore becomes the sampling time, since the sampling flow rate is constant or does not vary greatly.

For this reason, some standards specify that the sampling time is dependent on both the:

- expected concentration of the stack gas
- limit of detection and range of the analytical procedure used by the laboratory

Therefore it is crucial that you consider the performance of the analytical end method when deciding on a suitable sampling time.

## Number of samples

The number of samples required for compliance is specified by environmental legislation and the regulatory authorities. However, the number of samples required when calibrating CEMS is specified in the European standard for Quality Assurance of CEMS (EN 14181).

In general, when measuring a stable emission, you should take a minimum of 3 consecutive samples, and each for a minimum duration of 30 minutes. This approach is often specified in regulatory guidance.

For manual techniques, you may need to sample for longer than 30 minutes to meet the limit of detection for the laboratory's analytical procedure.

If the individual sample time is significantly over 30 minutes, it may not be practical to complete 3 consecutive measurements in 1 day. You may be able to carry out a reduced number of tests, over a longer sample time, if you agree this with your regulatory authority. Examples of this could be when testing for mercury or dioxins and furans.

You do not need to do a minimum of 3 tests if you are measuring dioxins and furans at waste incineration plants. In this case, you must sample for between 6 to 8 hours duration to comply with regulations. Due to the length of this sample time, you can carry out a single test instead of 3 tests.

However, for other sectors, such as non-ferrous metals, you can have a shorter sample duration for dioxins and furans, so you will need to carry out 3 consecutive tests.

For unstable emissions, you should increase the number of samples. For compliance monitoring for regulatory purposes, your permit may specify the number of individual measurements required.

When you take a number of periodic measurements during a sampling campaign (for example, 3 consecutive tests), you can average these to provide an overall result. For compliance purposes, you may also average the measurement uncertainty associated with each result.

## Field blanks for manual sampling

Field blanks are an important part of quality control in manual sampling. They are used to make sure that no significant contamination has occurred during the measurement. This includes during:

- the equipment preparation
- transport
- installation on-site
- subsequent analytical work in the laboratory

CEN standard methods specify the minimum requirements for carrying out field blanks as part of a series of measurements.

A field blank is carried out close to the sample location, in an identical manner to the normal samples in the measurement series. However, you do not draw gas through the sample equipment.

Generally, the field blank is acceptable if it does not exceed 10% of the emission limit value (ELV). When using CEN methods, you do not deduct the field blank value obtained from the sample result(s).

## Limit of detection of the method

An important aspect of stack emission monitoring is the limit of detection (LOD) of the method used. The percentage uncertainty associated with a measurement increases the closer the result is to the LOD.

Some manual methods specify a LOD as a fixed percentage of the ELV (usually 10%). This provides a guide for selecting an appropriate sample time and helps minimise the uncertainty associated with a measurement result that is close to the ELV.

To make sure that you meet the method's LOD, you must liaise with the analytical laboratory to determine the detection limit of the analytical method. By using an estimate of the expected concentration of the monitored substance in the stack gas, you can calculate the sample time you need to make sure you meet the method's LOD.

## Instrument certified ranges

MCERTS provides the criteria for selecting CEMS based on certified ranges. In general, the lower the certified range, the better the CEMS is likely to perform. This is because the majority of performance standards are expressed as a percentage of the range.

You can find more detailed guidance in M20 quality assurance of continuous emissions monitoring systems (<https://www.gov.uk/government/publications/m20-quality-assurance-of-continuous-emission-monitoring-systems>).

Some MCERTS certified CEMS are classed as transportable instruments. These perform to the same standard as CEMS. They're used for manual stack emission monitoring activities, such as compliance monitoring and calibrating CEMS.

In general, you should select the certified range of the analyser for periodic instrumental techniques so that it meets the MCERTS certified range of less than:

- 1.5 × the daily ELV for incineration processes
- 2.5 × the daily ELV for large combustion plant and other types of processes

## Instrument zero and span operations

When using periodic instrumental techniques, you must zero and span the instruments to check that they:

- are working correctly
- have not drifted during the monitoring period

You should report the zero and span results with the measurement results. If the drift is greater than the value allowed in the applicable standard method, you should repeat the sampling.

The gases you use for calibration should be traceable to national standards. When carrying out multi-point calibrations, you should use gas dilution or blending systems that comply with the requirements of United States Environmental Protection Agency (US EPA) Method 205 (<https://www.epa.gov/emc>).

## Choice of monitoring method

This section is about the general principles for selecting the measurement method. Each may have its own advantages or disadvantages related to performance and reliability.

Terms used to characterise the performance of an automated method include range, response or drift. These are defined in MCERTS performance standards for CEMS and transportable CEMS (<https://www.gov.uk/government/publications/mcerts-performance-standards-and-test-procedures-for-continuous-emission-monitoring-systems>). You must carefully consider these factors when selecting a suitable monitoring technique.

For periodic monitoring, the portability and size of equipment can limit the places you use them. Also, most monitoring equipment requires an electrical supply at the monitoring point. If you are complying with regulatory monitoring requirements, the standard method will usually be specified in your permit.

## Selecting standard methods

The amount of validation work carried out by different organisations during the development of a standard method will vary. Standards developed and published by CEN are comprehensively validated and are referred to as reference methods. However, other standards are important, as there are substances that are not covered by CEN standards.

You should use monitoring standards in the following order of priority:

- CEN
- International Standardisation Organisation (ISO)

You can use an alternative method provided you can demonstrate equivalence to the reference method by using EN 14793 – Determination of the equivalence of an alternative method with a reference method. For example, CEN TS 17021 describes an alternative method for measuring SO<sub>2</sub>.

The reference method for measuring emissions of SO<sub>2</sub> is a manual method which employs a wet chemistry technique. However, test laboratories may use an alternative method, as long as the test laboratory can demonstrate that it produces results of an equivalent quality to the reference method.

Alternative methods tend to be CEN technical specifications (these can become European standards, following a validation programme). You may use CEN technical specifications, such as CEN TS 17021, for compliance assessment monitoring and calibrating CEMS for EPR installations. This is provided you meet the requirements specified in the MCERTS performance standard.

If you cannot monitor the substance using standards covered by CEN or ISO, you can select a method from the following:

- British Standards Institution (BSI) (<https://shop.bsigroup.com/Navigate-by/Standards/>)
- US EPA (<https://www.epa.gov/emc>)
- Verein Deutscher Ingenieure (<https://www.vdi.eu/engineering/vdi-standards/>)

When a CEN method is published, BSI will adopt it and any equivalent BSI method will be withdrawn. BSI has adopted most, but not all, ISO methods.

If you cannot monitor the substance using the standards already mentioned, then you may adapt the following occupational methods. You must follow the requirements of ISO 17025 for stack emission monitoring.

- Method for the Determination of Hazardous Substances series published by the Health and Safety Executive (<http://www.hse.gov.uk/pubns/mdhs/>)

- National Institute of Occupational Safety and Health (<https://www.cdc.gov/niosh/index.htm>)
- Occupational Safety and Health Administration (<https://www.osha.gov/>)

One monitoring technique that is not covered by the standards already mentioned is using indicating detection tubes. These change colour due to a reaction with the tube contents and the substance being sampled. You can use detection tubes for a wide variety of substances. For example, they may be useful if a process requires frequent (such as daily) monitoring to check an abatement system is working properly. However, the results obtained are qualitative because you need to make a subjective decision to estimate changes in colour.

## **Collecting and reporting data and process conditions**

Many manual monitoring techniques require supporting raw data from the on-site sampling.

You should record site notes of relevant data (for example sample volumes) on the appropriate forms on-site. You should include them in the raw data section of the final results report.

Data from the analysis stage, if required by the method, will be provided later by a laboratory. Instrument-based methods provide real-time data, which you must record for immediate or later interpretation and reporting. This applies to CEMS and instruments used periodically. You may store the data on-site using a variety of systems. These can range from a simple chart recorder, to automatic data loggers able to communicate with a remote central processing unit.

## **Process conditions**

Before sampling at a site for the first time, you must review the site to understand the facility's process conditions, for example:

- material balance
- feedstock details
- percentage load

The MCERTS performance standard for organisations specifies this.

You should collate this information to form part of the site-specific protocol, which details the process conditions under which sampling should occur. You must record the process conditions during the sampling campaign to make sure that they are the same as those specified in the site-specific protocol.

## **Measurement uncertainty**

Measurement uncertainty is the range of values in which you will find the true value of a measurement with a specified level of confidence.

The true value is a conceptual term, which you can never exactly determine. All measurements have associated uncertainty; the goal is to quantify this uncertainty so that you can properly interpret the results. In the case of many stack measurements, you need to show that the measurement is fit for purpose by demonstrating that the uncertainty of the measurement is within certain criteria.

The statement of uncertainty includes a value for the level of confidence. This quantifies the probability that the true value lies within the region defined by the confidence interval. The measurement uncertainty defines the size of the region in which the true value is expected to lie. The confidence interval defines how likely this is.

For example, the following measurement result has a level of uncertainty: NO<sub>2</sub> concentration = 45 ± 4 mg/m<sup>3</sup>.

Factors contributing to the uncertainty mean that it is not justifiable to say the concentration is certain to be in the range 41 to 49 mg/m<sup>3</sup>.

However if the uncertainty of 4 mg/m<sup>3</sup> was calculated with a level of confidence of 95% you can assume that 95 times out of 100 the result would be within those bounds. This enables regulatory bodies to interpret measurements and their uncertainties and assess whether limit values are being complied with.

There are other concepts which are important in understanding uncertainty. These include the concept of random and systematic sources of uncertainty.

Random sources of uncertainty are those which change in a random manner between successive measurements, during the period of measurements. You can reduce the influence of random sources of uncertainty by taking multiple measurements and averaging the results. The random component of a measurement uncertainty is sometimes referred to as the precision of the method used.

Systematic sources of uncertainty are those that remain unchanged during the period of measurements. Increasing the number of measurements does not necessarily reduce the effects of these sources of uncertainty.

The effect of systematic uncertainties on a measurement result is sometimes referred to as the 'bias' of the method used.

The terms repeatability and reproducibility may also be used as properties of a measurement method.

Repeatability means the random variations observed when an analyst in one laboratory carries out a measurement. Reproducibility is the random variations seen between the results of different laboratories or analysts.

These methods of describing uncertainty do not apply to CEMS, though they may still be encountered in manual stack sampling methods.

## **Procedure for calculating uncertainty**

There are a number of sources of uncertainty associated with any particular measurement. The goal in calculating uncertainty is to account for and quantify the effect of all significant sources.

A generic approach to calculating uncertainty is described in the Guide to the Expression of Uncertainty in Measurement (<https://www.bipm.org/en/publications/guides/gum.html>) (GUM). In this procedure, you identify, quantify and combine individual uncertainty sources to provide the measurement uncertainty.

This procedure has been adopted as the main approach by the European and international standardisation bodies and will be used in standardised measurement methods.

You should use the GUM approach. The steps you should take are:

- review the measurement method and identify potential sources of uncertainty
- quantify the significant sources of uncertainty
- combine the uncertainty components and expand to give the required level of confidence
- report the measurement uncertainty with the measurement result

## **Determine potential sources of uncertainty**

The first stage in determining the uncertainty of a measurement is to fully understand the method being followed to produce the final result. For example, is the measured quantity the concentration of the stack gas or a mass emission rate? It is important to consider all the sources of uncertainty that may contribute to the final result, not just those which relate to the measurement of gas concentration.

You should note that process variability does not contribute to measurement uncertainty.

You may be able to control (or correct for) some sources of uncertainty as part of the measurement procedure. For example, you can calibrate an instrument which is affected by changes in atmospheric pressure frequently enough to account for ambient pressure changes. However, you must include these sources until you can show they are insignificant.

## **Quantify the significant uncertainty sources**

In many cases, what you will know about the uncertainty source is the variation of an influence factor, for example the:

- stack gas temperature
- range of an interferent gas in the stack

In these cases you need to:

- determine the sensitivity of the measurement to the influence
- derive the sensitivity coefficient, usually by experiment

You can obtain these from the tests that CEMS undergo as part of obtaining MCERTS certification, or from data published in standard reference methods.

You then calculate the uncertainty contribution of such influences from the variation of the influence quantity, multiplied by the sensitivity coefficient.

It is good practice (where possible) to correct such an influence, for example by measuring temperature online, then correcting the result. There will still be a (smaller) uncertainty contribution due to measuring and applying the correction.

You should carry out a review of the potential uncertainty sources to identify any that are insignificant. You can then discount these from further evaluation. You can generally discount any uncertainty source which contributes less than 10% of the largest uncertainty source.

Where a standard method provides information on the uncertainty of the results and you are following it exactly, you may directly quote the uncertainties given in the standard. But, you must determine additional sources of uncertainty in addition to those quoted in the method, for example, those due to:

- flow measurements used to convert results to stack emission rates
- variations from the method

In some cases the measuring instrument is calibrated against a standard reference method on-site. You should use the uncertainties due to the standard reference method, and the calibration procedure, to determine the uncertainty of the results.

You should express the individual uncertainties as standard uncertainties or variances. The procedures used to do this are described in ENV 13005:1999 (<https://www.en-standard.eu/ilnas-p-env-13005-guide-to-expression-of-uncertainty-in-measurement-1/>)

GUM (<https://www.bipm.org/en/publications/guides/gum.html>) has guidance on estimating uncertainty for analytical measurements. Also see the standard ISO 14956 (Air quality – evaluation of the suitability of a measurement procedure by comparison with a required measurement uncertainty). This provides a procedure for calculating the uncertainty of instrumental measurement methods based on performance characteristics.

Two terms are used in GUM to describe how uncertainty sources are evaluated, Type A and Type B.

GUM distinguishes between:

- uncertainties derived from statistical analysis (the variance) of repeated measurements (Type A)
- those derived by other means (Type B)

In stack monitoring we do not always have repeated measurements and many sources of uncertainty are Type B. GUM describes how to calculate the standard uncertainties for both types. There is also no difference in the way the standard uncertainties derived from Type A and Type B terms are subsequently treated in the calculation of the combined measurement uncertainty.

## Calculating the measurement uncertainty

The standard uncertainties are combined as the root sum of squares to derive the combined standard uncertainty. All standard uncertainties are combined in the same way. This is regardless of whether they are due to uncertainty sources which are Type A or Type B and random or systematic.

ISO 14956 (Air quality – evaluation of the suitability of a measurement procedure by comparison with a required measurement uncertainty) provides a technique for accounting for the correlation you may expect between interfering gases present in the stack. You then multiply the combined standard uncertainty by a coverage factor (generally known as  $k$ ) to provide the required level of confidence in the uncertainty estimation. A level of confidence of 95% is usually required, and in most cases a coverage factor of  $k = 2$  is used. GUM provides procedures to determine the value of  $k$ .

Some approaches to estimating uncertainty or components of uncertainty in practice are:

- repeat measurements using reference materials – this does not cover the effects of influences not present during these measurements (for example stack gas conditions and sampling losses) and you must determine these separately
- experimental work (for example, repeatability experiments, paired comparisons and ring tests)
- estimating based on previous results or data (for example, instrument manufacturers' specifications, calibration data and proficiency-testing schemes)

Where you are using previous work, particularly standard methods, to provide uncertainty estimates, you must know what:

- conditions the uncertainty estimate is appropriate for
- aspects of the measurement are covered

For example, standard methods may quote ‘internal uncertainty’ and ‘external uncertainty’, which correspond to repeatability and reproducibility, respectively. These measures were determined under particular conditions, and may be applicable if similar conditions are present during subsequent measurements.

If you have followed the method exactly, then you may include these values from the standard in an uncertainty determination. You should recognise that these parameters may not include all the potential influence factors and other sources of uncertainty that may be present under stack conditions. It is therefore recommended that you carry out an uncertainty estimation for the specific measurement.

## **Non-compliant sample locations**

In some circumstances, it may be difficult to follow the requirements of isokinetic methods (sampling at multiple points in a stack) because of the sample location. There may be:

- limited access to the required number of sample lines
- limited access to sample points, which may restrict the number of points you can use
- poor positioning of the sample plane, which may result in failing to meet the flow criteria

Unfortunately, you cannot quantify the effects of these factors on the measurement uncertainty. Which means you cannot take them into account when reporting the results. The reported uncertainty is based on the measurement method only and does not take into account that the sampling location does not comply with the standard.

The only practical option in these cases is to include qualifying remarks in the monitoring report, stating that the deviations from the isokinetic method are due to the non-compliant sampling location. Make it clear in the report that the results were not produced in full compliance with the method.

## **Calibration of CEMS**

Before you calibrate a CEM, you must check it is functioning and verify its performance. Typical performance checks include:

- leak test
- response time
- linearity
- interference, particularly any substances which could cause bias
- zero and span drift
- comparison with a reference method

Checking the functionality and verifying the performance of CEMS is covered by European standard EN 14181, Stationary source emissions – quality assurance of automated measuring systems (<https://shop.bsigroup.com/Navigate-by/Standards/>).

EN 14181 was developed primarily for waste incinerators and large combustion plants. There is further guidance in M20 Quality assurance of continuous emission monitoring systems (<https://www.gov.uk/government/publications/m20-quality-assurance-of-continuous-emission-monitoring-systems>).

This standard consists of 3 quality assurance levels (QALs) and an annual surveillance check (AST).

## QAL 1

This is a procedure to demonstrate that the CEMS is suitable for the intended purpose before it is installed. It has to meet required performance standards and uncertainty budgets.

## QAL 2

This covers the quality assurance of the installation and includes:

- a selection of performance tests and functionality checks
- a comparison of CEMS measurements against a reference method with a known uncertainty

The comparison includes 15 or more repetitions of the reference method in order to calculate a calibration function by linear regression.

QAL 2 therefore specifies a statistical technique to determine the total expanded uncertainty of the CEMS. You should use this to determine compliance with the specified uncertainty budget allowed for a 95% confidence interval.

## QAL 3

This is the determination of a periodic zero, span drift and precision.

## AST

This is a simplified QAL 2 check, using 5 or more repetitions of the reference tests to check the continuing validity of the calibration function.

Ongoing quality assurance for processes that do not need to meet the full requirements of EN 14181 should follow its principles, but a reduced number of parallel measurements may be acceptable.

To calibrate particulate CEMS, you can use the following:

### Spread of data

Spread > 15% of ELV:

- functional tests annually: linearity, response time, system integrity
- verify that CEMS read zero at zero emissions
- 9+ periodic reference method repetitions over 2 or more days
- calibration function plus statistical tests

### Medium to high level cluster

Emissions higher than 30% of daily average ELV:

- functional tests annually: linearity, response time, system integrity
- verify that CEMS read zero at zero emissions
- 5 periodic reference method repetitions over 1 day
- average of periodic reference method repetitions and CEMS data to derive a calibration factor

## Low-level cluster

Emissions not more than 30% of daily average ELV; linear regression produces  $R^2 < 0.9$ :

- functional tests annually: linearity, response time, system integrity
- verify that CEMS read zero at zero emissions
- 3 periodic reference method repetitions over 1 day
- calibrate with surrogates if possible – if not, then set the CEMS gain factor to respond to process changes

For CEMS that measure gases, you can apply the following:

- functional tests annually as specified in EN 14181
- 5 x 30 minute periodic reference method repetitions over 1 day
- calibration function plus statistical tests
- establish a QAL 3 procedure to check drift and precision

## Quality assurance of predictive emissions monitoring systems

A predictive emissions monitoring system (PEMS) predicts real time emissions levels from a model based on previous stack emission results. This provides an alternative to carrying out ongoing stack emissions measurements.

A PEMS uses a model to correlate process parameters to stack emission results. A well-developed model is based on being able to vary the process, while recording process parameters and emissions results.

The reliability of a PEMS is based on the premise that the assumptions used when developing the model remain valid during the ongoing operation of the process.

You need to verify a PEMS by parallel reference testing – you must measure the emissions using MCERTS accredited measurements, over a range of load points. The procedure you use should follow similar general principles to those used during QAL 2 of EN 14181.

To date, the evidence from field experience is that using a PEMS can be a valid approach for predicting emissions of NO<sub>x</sub> and CO. This is especially the case for smaller gas turbines, such as those below 50MW rated thermal input.

The evidence for other types of installations and determinands is limited. Therefore, you need to prove and validate the PEMS on each installation you use it on. PD CEN 17198 has the requirements for certifying PEMS software and for assuring the performance and quality of the PEMS for specific applications.

## Reporting

For periodic monitoring, you must carry out reporting following the requirements in the [MCERTS](#) performance standards for organisations undertaking stack emission monitoring.

## Safety

There are hazards associated with carrying out stack emission monitoring on-site. See M1 sampling requirements for stack emission monitoring (<https://www.gov.uk/government/publications/m1-sampling-requirements-for-stack-emission-monitoring>) for a description of some of the common hazards.

Published 18 December 2019

## Related content

- Monitoring stack emissions: environmental permits (<https://www.gov.uk/government/collections/monitoring-stack-emissions-environmental-permits>)
- Monitoring stack emissions: techniques and standards for periodic monitoring (<https://www.gov.uk/government/publications/monitoring-stack-emissions-techniques-and-standards-for-periodic-monitoring>)
- M1 sampling requirements for stack emission monitoring (<https://www.gov.uk/government/publications/m1-sampling-requirements-for-stack-emission-monitoring>)
- MCERTS: performance standard for manual stack emission monitoring organisations (<https://www.gov.uk/government/publications/mcerts-performance-standard-for-organisations-monitoring-manual-stack-emissions>)

## Collection

- Monitoring stack emissions: environmental permits (<https://www.gov.uk/government/collections/monitoring-stack-emissions-environmental-permits>)
- Monitoring emissions to air, land and water (MCERTS) (<https://www.gov.uk/government/collections/monitoring-emissions-to-air-land-and-water-mcerts>)

## Explore the topic

- Environmental permits (<https://www.gov.uk/topic/environmental-management/environmental-permits>)