

**Technical Guidance Note
(Monitoring) M20**

**Quality assurance of continuous emission monitoring
systems - application of EN 14181 and BS EN 13284-2**

**Environment Agency
Version 2.4
April 2012**

Foreword

We have issued Technical Guidance Note (TGN) M20 within our series of TGNs, which provide monitoring support to our regulatory officers, as well as process operators, test laboratories, equipment suppliers, and those with interests in emissions monitoring. M20 supports the application of *EN 14181, Stationary source emissions – quality assurance of automated measuring systems*, and a related standard, *BS EN 13284-2, Stationary source emissions - Determination of low range mass concentration of dust - Part 2: Automated measuring systems*.

M20 provides guidance on:

- monitoring requirements of EC Directives for large combustion plant and waste incineration;
- choosing Continuous Emission Monitoring Systems (CEMs) that meet the performance requirements of these EC Directives;
- demonstration of suitability through MCERTS product-certification;
- determining whether CEMs meet the uncertainty allowances specified by the above EC Directives;
- assuring that CEMs are located in the optimum position;
- functional tests to assure that CEMs have been installed and are operating correctly;
- calibration using a Standard Reference Method (SRM);
- on-going surveillance to assure the correct operation of CEMs, by examining drift and precision during continuous operation;
- annual surveillance tests of CEMs.

The TGN is in five sections, covering:

- regulatory background to EN 14181 and BS EN 13284-2;
- suitability, selection and installation of CEMs;
- functionality and calibration of CEMs;
- on-going quality assurance of CEMs;
- annual surveillance tests for CEMs.

For anybody carrying out work under EN 14181 and 13284-2, we recommend that you read this TGN in conjunction with the standards and their associated Method Implementation Documents (MIDs) we have published. In particular, test laboratories performing QAL2s and AST must be accredited to the MID for EN 14181.

We have updated this TGN following extensive experience with EN 14181. In addition to several further editorial changes and points of clarification, we have included more guidance on performing the functional tests.

Feedback

Any comments or suggested improvements to this TGN should be e-mailed to Rick Gould at richard.gould@environment-agency.gov.uk. All our guidance notes and details of MCERTS can be found at www.mcerts.net.

Record of Amendments

Version number	Date	Section	Amendment
Version 1	September 2005	-	First publication
Version 2	August 2008	-	Editorial changes and points of clarification throughout the TGN.
Version 2	August 2008	1.4.2	Clarification of roles.
Version 2	August 2008	2.2.1	Clarification of the meaning and requirements for ranges.
Version 2	August 2008	3.5.1	Inclusion of guidance on low-levels of emissions.
Version 2	August 2008	3.5.2	New section on monitoring strategy and different levels of emissions.
Version 2	August 2008	3.5.3	New section of instructions on dealing with low levels of particulate emissions.
Version 2	August 2008	3.5.5	New section providing guidance on lag times.
Version 2	August 2008	3.5.17	New section providing guidance on replacement CEMs.
Version 2	August 2008	3.5.18	New section on cross-calibration for back-up CEMs.
Version 2	August 2008	3.9	Clarification of guidance on extending the calibration range.
Version 2	August 2008	4.1.2	Clarification of guidance on calculating s_{AMS} for QAL3 control charts.
Version 2	August 2008	4.2.4	Clarification on adjustments of CEMs following span checks.
Version 2	August 2008	Annexes	The examples have been removed, for updating and publication in a supplementary workbook.
Version 2.1	September 2008	2.3.2	Correcting the entry for gaseous fuels in Table 2.
Version 2.1	September 2008	3.4.2	Clarification of the effects of Article 13 on functional tests.
Version 2.1	September 2008	3.5.16	Correcting the specification for test gases for HCl and HF from 2% to 5%.
Version 2.1	September 2008	4.2.6	Adding a new sub-section to clarify the effect of QAL3 operations at WID installations.
Version 2.1	September 2008	4.3.4	Deleting the entire sub-section as examples will now be contained in a supplementary workbook.
Version 2.2	June 2010	All	Clarification of requirements throughout the TGN.
Version 2.2	June 2010	1.3	Clarification of sampling system requirements.
Version 2.2	June 2010	1.4.1	Requirement for accreditation to EN 14181.
Version 2.2	June 2010	1.4.2	New provisions for functional tests and who performs them.
Version 2.2	June 2010	3.2.1, 3.2.2	References to EN 15259 and the corresponding MID, instead of references to ISO 10396.
Version 2.2	June 2010	3.4.2	Clarification of new provisions for functional tests and who performs them.
Version 2.2	June 2010	3.5.1	Orientation of axes when reporting the results of linearity tests.
Version 2.2	June 2010	3.5.2	Clarification of strategy for QAL2 and AST sampling, and adjusting monitoring periods.
Version 2.2	June 2010	3.5.8(9)	Guide on dealing with potential divide-by-zero errors when oxygen levels increase.
Version 2.2	June 2010	3.5.10(11)	Requirements for the number of data points when using instrumental SRMs.
Version 2.2	June 2010	3.5.11(12) 3.5.12(13)	Reference to Method C for dealing with low-level clusters.
Version 2.2	June 2010	3.5.16(17)	Clarification on the use of R^2 for calibration functions,

Version number	Date	Section	Amendment
			and when to apply calibration functions.
Version 2.2	June 2010	3.9	Including provisions for extending the calibration function when it is impossible to determine the optimum time for performing a QAL2.
Version 2.2	June 2010	4.2.5	Clarification of procedures when changing QAL3 reference materials.
Version 2.2	June 2010	4.3.2	Relaxing the warning and alarm points for Shewhart charts, when very small changes could trigger unnecessary action.
Version 2.2	June 2010	Annex 1	New annex, on the functional tests.
Version 2.2	June 2010	Annex 2	New annex, on additional k_v values for the variability tests.
Version 2.3	June 2010	3.5.13	Amended uncertainty requirement for all test gases, to 2%, to reflect current CEN standards.
Version 2.3	June 2010	3.5.18	Amended uncertainty requirement for all test gases, to 2%, to reflect current CEN standards.
Version 2.4	April 2012	Whole document	Change reference from BS EN 14181 to EN 14181.
Version 2.4	April 2012	1.2.2	New sub-section on the application of EN 14181 to emissions trading schemes.
Version 2.4	April 2012	Table 1	Clarification of responsibilities and roles of the regulator.
Version 2.4	April 2012	2.3.2, 1 st Note	Cross-reference to 2.3.4 for NO _x monitoring.
Version 2.4	April 2012	2.3.3, 1 st Note 3	Note 3 deleted.
Version 2.4	April 2012	2.3.4	New sub-section on NO _x monitoring.
Version 2.4	April 2012	2.3.4	Relabelled 2.3.5 due to new sub-section 2.3.4.
Version 2.4	April 2012	3.2.1	Clarification of requirements for homogeneity test through application of EN 15259.
Version 2.4	April 2012	3.4.1	Clarification of requirements for NO _x converter efficiency-tests.
Version 2.4	April 2012	3.4.2, Key Points	Clarification of requirements for functional tests.
Version 2.4	April 2012	Figure 5	Note added clarifying recommendation to perform a linearity test for QAL2.
Version 2.4	April 2012	3.5.4	Requirement for accreditation to the MID for EN 14181 emphasised. Clarification of application of SRMs for NO and total NO _x .
Version 2.4	April 2012	3.5.5	Edited to clarify requirements.
Version 2.4	April 2012	3.5.7	Edited to clarify requirements.
Version 2.4	April 2012	3.5.11(ii)	Outliers procedure standardised using RM-QG14.
Version 2.4	April 2012	3.5.13	Clarification of test-gas requirements.
Version 2.4	April 2012	3.5.15	Virtual ELV for moisture raised from 25% to 30%.
Version 2.4	April 2012	3.5.17	Stating an ELV and 95% confidence interval for ammonia.
Version 2.4	April 2012	3.5.19	Procedure for dealing with repaired and replaced CEMs clarified.
Version 2.4	April 2012	3.6	Clarification of required frequency for QAL2.
Version 2.4	April 2012	3.9.3	New sub-section describing requirements for test gases.
Version 2.4	April 2012	3.9.4	New sub-section describing requirements for test reports.
Version 2.4	April 2012	4.2.1	Reference to BS 4559 changed to its European equivalent, ISO 6142, to ensure consistency with the rest of TGN M20.

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Quality assurance of continuous emission monitoring systems – application of EN 14181 and BS EN 13284-2

1 General guidance on quality assurance and calibration

1.1 Introduction

The primary role of this Technical Guidance Note (TGN) is to provide guidance on the application of European Standard *EN 14181, Stationary source emissions – Quality assurance of automated measuring systems*¹ and a supporting standard, *BS EN 13284-2, Stationary source emissions - Determination of low range mass concentration of dust - Part 2: Automated measuring systems*² on installations falling under the European Directives for the incineration of waste (2000/76/EC³), and large combustion plants (2001/80/EC⁴). In this TGN these Directives will be abbreviated to the WID and LCPD respectively. The above standards use the term Automated Measuring Systems (AMS) instead of the term CEMs.

Both Directives specify the use of international and national standards for monitoring, and define performance requirements for CEMs through specified *uncertainty budgets* or *allowances* for accuracy and precision. EN 14181 and BS EN 13284-2 were developed to support the quality assurance of monitoring requirements for these Directives, by including provisions to ensure that CEMs meet the required performance specifications both before and after installation.

For simplicity, throughout this document reference to EN 14181 will also refer to BS EN 13284-2.

Key point

This TGN summarises the requirements of EN 14181 and BS EN 13284-2, and provides guidance on how to perform each of the required tasks. For anybody carrying out work under EN 14181 and 13284-2, this TGN should be read in conjunction with these standards and their associated Method Implementation Documents (MIDs).

1.2 Regulatory framework and standards for monitoring

1.2.1 Monitoring requirements in the WID and LCPD

The WID and LCPD specify performance standards for monitoring in two ways. Firstly, the Directives prescribe the use of CEN standards for monitoring and calibration, or if CEN standards are not available, then the use of ISO, national or other equivalent international standards that will provide data of a suitable quality. Many of these standards include performance specifications for CEMs.

Secondly, these EC Directives specify overall performance requirements for both continuous and discontinuous monitoring through uncertainty allowances expressed as a percentage of the ELV. These uncertainty allowances are expressed as a 95% confidence interval (CI) and specify overall requirements for accuracy and precision.

Key Points

- **Monitoring under the WID and LCPD must be performed according to the requirements of CEN standards, or ISO, national or other international standards if CEN standards are not available. The standards are stated in TGN M2.**
- **The WID and LCPD specify requirements for monitoring accuracy and precision through 95% confidence intervals.**

1.2.2 Emissions trading schemes

The EU Emissions trading scheme (EU-ETS) and Clean Development Mechanism (CDM) applied through the Kyoto Protocol include provisions for applying EN 14181. For example, emissions of nitrous oxide (N₂O) require continuous monitoring and as such, the CEMs require quality assurance through the application of EN 14181. These provisions are likely to strengthen in future years.

1.3 Scope and structure of EN 14181

EN 14181 applies only to CEMs used for compliance monitoring, and permanently installed at WID and LCPD installations. It does not apply to portable CEMs, such as those used in SRMs, or CEMs used in PPC installations outside the scope of the WID and LCPD. The requirements for such CEMs, or SRMs which used instrumental techniques, are described in other applicable standards for monitoring.

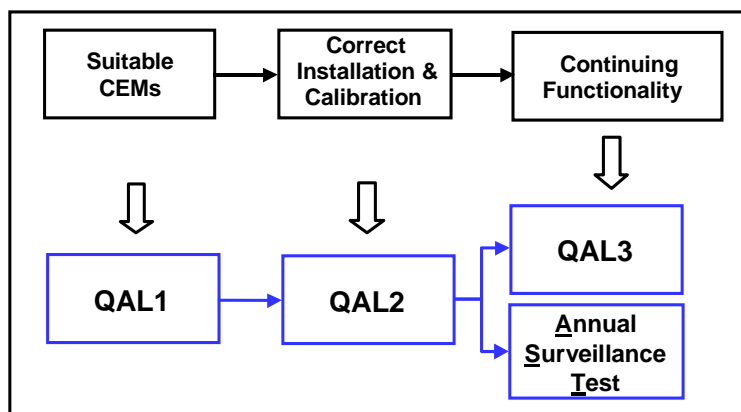
Also EN 14181 only applies to the CEMs themselves and not the data collection and recording systems used with CEMs.

EN 14181 specifies three quality assurance levels (QALs) and an annual surveillance test (AST). These are:

- QAL1 A procedure to demonstrate that the CEM is suitable for the intended purpose before installation, by meeting required performance standards and the uncertainty allowances specified in EC Directives.
- QAL2 A procedure to calibrate the CEM once it has been installed, using SRMs and then verify whether it still meets the required uncertainty allowances, once installed.
- QAL3 A procedure to maintain and demonstrate the required quality of the CEM during its normal operation by checking the zero and span readings.
- AST A procedure to evaluate the CEM to show that it continues to function correctly and the calibration function is still valid.

These quality assurance levels follow a logical sequence to demonstrate the suitability of the CEM, its correct installation, commissioning, and calibration, followed by continuing and correct operation (see Figure 1).

Figure 1 – the sequence of quality assurance levels in EN 14181



QAL 1

The first level of quality assurance, QAL1, demonstrates the potential suitability of the CEM before it is installed on a stack. In England and Wales, MCERTS product certification at an appropriate certification range (see sections 2.2 and 2.3) is taken as evidence of compliance with the QAL1 requirements. When a process operator commissions the installation of a CEM, it is essential to ensure that the sampling system is the same type that was certified under MCERTS.

In order to meet the requirements of the WID, LCPD and EN 14181, CEMs must meet certain performance requirements evaluated under our Monitoring Certification Scheme (MCERTS). Among other things, under these requirements, once the CEMs have been installed, CEMs must have the means for: tests for linearity; zero drift and span drift checks; and provisions for leak-checking the entire system.

The WID and LCPD specify uncertainty allowances expressed as 95% Confidence Intervals (CIs). Whilst the procedure for determining uncertainties is described in BS EN ISO 14956⁵, making use of performance testing data, the procedure is both complex and prone to differing interpretations. Therefore our approach is to make use of the known linear relationship between uncertainty allowances and certification ranges, whereby the suitability of a CEM is determined by using certified ranges. This simplified yet proven approach is described in section 2.

QAL 2

The second level of quality assurance, QAL2, specifies procedures to verify that the CEM has been installed correctly, verified, calibrated using SRMs, and checking that the CEM still meets the uncertainty requirements of the EC Directives. The correct installation and functionality of the CEM is verified through inspection and through a set of functional tests, examining performance characteristics such as response time and linearity.

The calibration of CEMs using SRM parallel measurements has two important roles in QAL2; firstly, the SRMs verify that the CEMs are reading correctly, or if not, then the reason for the discrepancy can be identified. If faulty, then the CEM can be repaired. Secondly, if there is a bias in the readings, then the SRM data can be used to calculate a calibration function for the CEM. The uncertainty of the installed CEM is then determined by calculating the variability of the calibration function. The effectiveness of this test requires at least fifteen repetitions of each applicable SRM spread out over at least three days.

In order to provide for the functional tests, among other things, an installed CEM must have the means for performing linearity tests, leak checking sampling systems for extractive CEMs, and QAL3 records to demonstrate that the CEM is stable prior to testing (ordinarily at least three months of QAL3 records).

Once installed, the uncertainty of the CEM's measurements may increase due to specific (and sometimes unique) factors at the installation, such as the position of the CEM or its sampling system, environmental conditions, stack gas conditions and uncertainties of calibration gases. Therefore, depending on the intended application, care must be taken in choosing a CEM to ensure it will meet the QAL 2 requirements at that specific installation.

The QAL2 procedures are carried out when:

- the CEM is installed;
- then at least every three years (under the WID) or five years (under the LCPD);
- whenever there is a significant change in plant operation which changes the emissions;
- after a failure of the CEM so that significant repair is required and affects calibration;

- after a significant upgrade or other significant change to the CEM affecting calibration.

Any changes that do not affect the calibration of the CEM will not require a repeat of the QAL2 procedure. Further guidance on significant changes is given in section 3.8.

QAL 3

The QAL3 procedure ensures that the CEM remains within the required specifications during continued use. QAL3 achieves this by requiring the plant operator to regularly measure the drift and precision of the CEM. This data is then plotted using control charts – such as Shewhart or CUSUM charts – and then using the outputs of these charts to determine when the CEM needs maintenance. The frequency of the drift measurements depends on the maintenance interval determined during the MCERTS⁶ performance tests, and can be anything from one week to several months.

The use of CUSUM charts, however, requires drift tests to be carried out at least weekly. In many CEMS the QAL 3 tests are conducted automatically within an instrument and therefore occur more frequently; with such systems, the data from these automatic zero and span checks needs to be available for the QAL3 procedure, unless the operator performs additional, manual zero and span checks.

Therefore in order to comply with the QAL3 requirements, all CEMs must have the means to allow operators and test laboratories to perform regular zero and span tests, or to have available the data from automatic zero and span checks. If the CEMs do not have such a means, then they cannot comply with the QAL3 requirements of EN 14181. The QAL3 requirements apply to peripheral measurements as well, although this would ordinarily only mean zero and span measurements for oxygen and moisture-monitoring systems (if applicable). Additionally, both extractive and in-situ/cross-stack systems require QAL3 checks.

AST

The annual surveillance test (AST) is a mini-QAL2 test. Its key objective is to check whether the calibration function determined during the QAL2 tests is still valid. The AST consists of the same functional tests as those used in QAL2, but the calibration function is checked by using a smaller number of repetitions of the SRMs (typically five to ten repetitions). If the calibration function is still valid, then no further action is required. If the AST shows that the calibration function is no longer valid, then a full QAL2 is required. However, small amounts of apparent bias may be acceptable, if they fall well within the uncertainties specified in the WID and LCPD.

In order to provide for the functional tests, among other things, a CEM must have the means for performing linearity tests, leak checking the entire system, and auditable QAL3 records.

Key Points

- **The SRMs during the QAL2 tests are not simply used to derive a calibration function, but also to verify whether the CEMs are providing reliable readings and within the allowable uncertainties specified by the WID and LCPD.**
- **If the SRMs reveal a bias in the readings from the CEM, then the SRM data is used to derive a calibration function to compensate for the bias.**
- **All CEMs must have the readily-available means for performing zero, span, linearity tests, leak checking the entire system and QAL3 records to demonstrate that the CEM is stable once the CEMs have been installed.**

1.4 Roles, responsibilities and delegation of responsibilities

1.4.1 Roles and responsibilities

The responsibilities of CEMs manufacturers or suppliers, test laboratories, process operators and the regulator under EN 14181 are shown in Table 1.

Table 1 – Actions and responsibilities within EN 14181

Organisation	Roles and requirements
CEMs manufacturers and suppliers	<ul style="list-style-type: none"> • Achieving and maintaining certification of CEMs to the applicable MCERTS performance standards • Supplying, correctly installing, commissioning and maintaining appropriate, MCERTS-certified CEMs to applicable installations • Installing CEMs in a manner which assures their integrity and correct operation to the required performance standards • When appropriate, co-operating with process operators and test laboratories to perform the functional tests and calibrate CEMs
Test laboratories	<ul style="list-style-type: none"> • Achieving and maintaining accreditation to ISO 17025 and the MCERTS performance standards, for the applicable SRMs • Performing the SRMs for the QAL2 and AST procedures • Reporting the results of the functional tests specified for the QAL2 and AST procedures • From the beginning of 2011, test laboratories must also be accredited to EN 14181. • Notifying the operator that the operator is responsible for ensuring that the functional tests are performed before each QAL2 and AST, regardless of who subsequently performs the functional tests.
Process operators	<ul style="list-style-type: none"> • Using CEMs certified to the appropriate MCERTS performance standards • Performing the QAL3 procedures • Ensuring that the functional tests are performed before each QAL2 and AST. • Submission of QAL2, QAL3 and AST reports as required by the regulator • Applying a procedure for QAL3; maintaining QAL3 records, other records and information as specified within EN 14181, and retaining QAL2 and AST reports for periods specified by the

Organisation	Roles and requirements
	regulator
Regulators	<ul style="list-style-type: none"> • Specifying EN 14181 requirements within permits or variations to permits • Assessing operator compliance • Assessing test laboratories for compliance with the MID for EN 14181 • Providing guidance on EN 14181

Key Points

- **Process operators have overall responsibility for complying with EN 14181.**
- **The SRMs for the QAL2 and AST must be performed by test laboratories accredited to ISO 17025, the MCERTS performance standard for stack emission monitoring, and the appropriate test methods.**
- **Test laboratories must also be accredited to EN 14181, through the MID for EN 14181.**

1.4.2 Delegation of roles

The requirements of EN 14181 are complex and we recognise the need for both co-ordination and co-operation between all organisations involved in the work. Our preference is for test laboratories to undertake all of the activities specified in QAL2 and the AST. However, we also recognise the need for flexibility, so any organisation may perform the functional tests specified in QAL2 and the AST, subject to certain requirements of quality assurance and control. Further details are provided in Section 3.4.1.

2 Suitability of CEMs (QAL1) and MCERTS

2.1 Basic rules for selecting CEMs

The following guidelines apply when selecting CEMs:

Determinands	The CEM is to be MCERTS certified for the determinands specified in the WID or LCPD where continuous monitoring is required.
Certification ranges and measurement ranges	The CEM is to be certified for a range that is suitable for the application (see sections 2.2 and 2.3).
Stack gas conditions	The operator should ensure that specific site conditions do not reduce the performance of the CEM to below required standards.
Proven suitability	The operator is recommended to ensure that the intended CEM is proven on comparable installations.
Functionality	All CEMs must have provisions that allow either operators, suppliers or test laboratories to perform zero, span and linearity tests once a CEM has been installed. New, extractive CEMs must have the means for leak checks, such as the provisions for applying test gases at the sampling probe to prove the integrity of the entire sampling system. Such provisions could also be used to test the response time of the entire system. We recommend that new systems have at least 3 months of QAL3 data to demonstrate that the CEM is stable before the QAL2 and AST exercises.
Particulate monitors	<p>Generally, particulate monitors may be sensitive to changes in flow rate, particle size distribution and changes in particle shape. Therefore the operator should determine whether specific stack conditions could potentially undermine the integrity of the monitoring data.</p> <p>The reference materials used in the automatic or manual zero and span check procedures (as required for QAL3) should be documented by the manufacturer and assessed as part of the MCERTS certification process.</p>

2.2 Suitable ranges

2.2.1 Measurement ranges and certification ranges

There is a difference between the certification range and the measurement range of the CEM. The measurement range is the set of values that the CEM can measure, from the lower detection limit (i.e. near zero) to a set upper limit. Within this measurement, the certification range is the smallest range over which the CEM can meet the MCERTS performance standards.

When CEMs are tested and subsequently certified, the MCERTS certificate states the *certified range*. In some cases a CEM may have more than one certification range. The MCERTS performance specifications are expressed as a percentage of the certification

range. Therefore in general, the lower the certified range, the better the performance of the CEM is likely to be. This is because the majority of performance standards are expressed as a percentage of the range. For example, if the performance requirement for cross-sensitivity is $\pm 4\%$ of the range and a CEM has a certified range of 0 to 75 mg.m^{-3} , then the cross-sensitivity will not be more than $\pm 4\%$ of 75 mg.m^{-3} , which is 3 mg.m^{-3} . A CEM with a certified range of 0 to 200 mg.m^{-3} may have a maximum cross-sensitivity up to $\pm 4\%$ of 200 mg.m^{-3} , or 8 mg.m^{-3} .

The main performance characteristic that is not range-dependent is linearity (or lack of fit). Therefore as an extra assurance, if a CEM is to be used for higher ranges than those certified, CEM manufacturers should ideally have had the linearity evaluated over the higher ranges during MCERTS testing. If this is not the case, then the linearity over the higher ranges should be evaluated either before installation or immediately afterwards.

Key Points

- **The measurement range of a CEM is the sweep of measured values between the lower detection limit (usually zero or near zero) and a defined upper limit.**
- **The certification range is the lowest range over which the CEM can meet the MCERTS performance specifications.**
- **Generally, CEMs with lower certified ranges will perform satisfactorily at higher ranges, since the lower the certified range, the better the performance.**

2.2.2 Suitability of measuring ranges to capture the expected variations in emissions

CEMs may be auto-ranging with respect to their measurement ranges, or they may have fixed, adjustable ranges; for example, the range may have settings at 0-100 ppm, 0-500 ppm and 0-1000ppm. The latter types of CEM typically have 4-20 mA analogue outputs. One drawback with such CEMs is that the CEMs have a lower resolution at the higher ranges. Therefore during performance testing for certification, the range is set at a value that will capture all the typical peaks in the emissions, but still maintain the required uncertainty at the ELV. For example, the range would be set at a value at least twice the half-hourly ELV of the intended application.

For applications, the range should also be set at a value which will capture all expected peaks in emissions, yet still meet the uncertainty requirements at the ELV. This is more of a challenge with CEMs that have adjustable ranges with a 4 – 20 mA analogue output. However, this is not usually a problem with CEMs which are auto-ranging and have digital outputs.

If there is any doubt about a CEM's performance for a particular application, reference should be made to the MCERTS test results.

2.2.3 Suitable certification ranges

The certification range can indicate the suitability of a CEM for a particular application. The WID and LCPD specify uncertainty budgets for certain determinands, so it is important to choose a CEM which will meet (and ideally exceed) these uncertainty specifications.

BS EN ISO 14956 specifies a procedure for calculating uncertainties. However, this procedure is complex. Therefore to simplify matters, our approach for selecting suitable CEMs is to apply range multipliers, whereby the lowest certified range is not more than 1.5x

the daily average (DA) ELV for incineration processes and not more than 2.5x the DA-ELV for large combustion plant and other types of process (or 48-h ELV for some installations under the LCPD). As there is a linear relationship between certified ranges and uncertainties, these multipliers provide assurance that CEMs with appropriate ranges will meet the uncertainty requirements specified in the WID and LCPD. This approach is now employed in EN 15267-3⁷.

The CEM shall also be able to measure instantaneous values over the ranges which are to be expected during all operating conditions. If it is necessary to use more than one range setting of the CEM to achieve this requirement, the CEM shall be verified for monitoring supplementary, higher ranges.

Note: Combined Cycle Gas Turbines (CCGTs) typically have a low ELV for NO_x, which means that the certified range for CEMs would be correspondingly low. There are certified CEMs available which have suitably low certified ranges for CCGTs. Therefore for new CEMs at CCGTs, the CEMs should meet the certified range requirements. Existing CEMs may be retained if they do not meet the requirements for certification ranges, as long as they meet the requirements for QAL2, QAL3 and the AST. Further details on the requirements for CEMs which measure NO_x are described in sub-section 2.3.4.

Key Point

When selecting a new CEM operators shall select a CEM with a certification range which is not more than 1.5x the daily average ELV for WID installations and not more than 2.5x the daily average ELV for LCPD installations. Measuring ranges should be set to capture the expected process variation.

2.3 Selection procedures for CEMs and sampling systems

2.3.1 CEMs already installed at a site

If CEMs already installed at an installation at the time the WID or LCPD permit is issued do not meet the requirements for ranges in section 2.2, then the CEMs may still be used if they fulfil the QAL2, AST and QAL3 requirements of EN 14181. In simple terms, CEMs with ranges higher than those required still may pass the QAL2, AST and QAL3 requirements, but the risk of failure increases as the certified range increases.

If the CEMs do not meet the QAL2, AST and QAL3 requirements and cannot be adjusted or modified to fulfil the requirements, then the operator will be required to replace them within one year with CEMs which do have suitable ranges based on the ELV multiplier rule.

2.3.2 New CEMs

New CEMs shall meet the requirements of the ELV multiplier rule. Also all new CEMs shall include the means to allow either operators, test laboratories or suppliers to perform zero, span and linearity tests once the CEMs have been installed.

Table 2 shows a selection of daily average ELVs for installations under the WID and LCPD, together with the certification ranges and allowable uncertainties.

Table 2 – Baseline ranges, ELVs and uncertainties

	ELV, mg.m ³	Certification range, mg.m ⁻³	Allowable uncertainty, %	Allowable uncertainty, mg.m ⁻³
NOx – incineration	200	300	20%	40
NOx – large combustion plant, solid/liquid fuel	200 - 600	500 - 1500	20%	40 – 120
NOx – large combustion plant, gaseous fuels	200 - 300	500 - 750	20%	40 – 60
NOx – large combustion plant, gas turbines	50 - 120	125 - 300	20%	10 – 24
SO ₂ – large combustion plant, solid/liquid fuel	200 - 850	500 - 2125	20%	40 – 170
SO ₂ – large combustion plant, gaseous fuels	35-800	88 - 2000	20%	7 – 160
SO ₂ – incineration	50	75	20%	10
CO – incineration	50	75	10%	5
HCl – incineration	10	15	40%	4
Particulate matter, large combustion plant	30 - 50	75 - 125	30%	9 - 15
Particulate matter, incineration	10	15	30%	3
Particulate matter, co-incineration	30	45	30%	9
Total organic carbon, incineration	10	15	30%	3

Note 1: NOx is expressed as NO₂. Therefore if a CEM measures NO alone, then the measurement must be converted to a NO₂ equivalent. For example, if the range for NO is 0 to 100 mg.m⁻³, then the range for an NO₂ equivalent (or total NOx) will be 0 to 153 mg.m⁻³.

Note 2: In practice the 48h limit for NOx for an existing plant under the LCPD is defined as *95% of the 48h means shall not exceed 110% of the ELV*. For example, if the ELV is 500 mg.m⁻³, then the uncertainty is based on a value of 550 mg.m⁻³.

2.3.3 Sampling systems for extractive CEMs

Extractive CEMs comprise the analyser(s) and additional devices for obtaining a measurement result. As well as the analyser(s) this includes the sampling system. It is the complete system, including the sampling system, that has been tested and certified.

There are several types of sampling system, such as:

- simple heated lines coupled to heated analysers that measure gases in a hot, wet form;
- heated lines and chiller-driers, delivering the sampled gases to the analyser in cooled, dry form;
- heated lines and permeation-driers, delivering the sampled gases to the analyser in cooled, dry form;
- dilution systems, although these are rarely used in the UK;
- the stack-mounted probe is coupled directly to a permeation drier, which then passes the cooled, dry sample gas via an unheated line to an analyser;
- there may be NOx converters to convert NO₂ to NO, in cases where the operator needs to monitor total NOx using an analyser which measures NO alone.

There are also many variations of these basic forms and as analysers are typically designed for use with specific types of sampling system, testing and subsequent approvals will certify a CEM with a stated type of sampling system.

As industrial processes often differ in their requirements, some flexibility is allowed in the selection of the sampling system with the CEM. However, the installed CEM must not deviate

from the type of sampling system specified on the certificate to ensure the CEM is not degraded, such that it no longer meets the required performance specifications.

Such allowable variations could include:

- a different length of sampling line to that which was tested;
- a different brand or model of sampling system, so long as there is evidence from third-party testing that the alternative components meet the required performance specifications and have been tested on analogous systems;
- additional manifolds and heated valves used to allow more than one analyser to share a sampling system.

Key Point

MCERTS and EN 14181 have provisions for systems integration. As long as sampling systems conform to the type originally tested and certified and there is evidence from third-party testing that the sampling system installed does not degrade performance below the MCERTS requirements, then the alternative sampling system is permitted as long as the sampling system is still the same type.

2.3.4 CEMs for NO_x

The Directives specify limits for NO_x as NO₂. However, most installations with ELVs for NO_x emit mostly NO. In such cases, it is acceptable for the operator to measure NO alone, and then apply a conversion factor to compensate for the small proportion of NO₂ in the stack gases, which is typically around 5% or less. This does not apply, however, to gas-turbines and some specific types of installation in the inorganic-chemicals sector, such as the production of nitric acid, fertiliser, and adipic acid.

The requirements for performing QAL2s and ASTs at installation which have ELVs for NO_x are described in sub-section 3.5.4.

2.3.5 Data-acquisition and handling systems (DAHS)

The scope of EN 14181 excludes data-acquisition and handling systems (DAHS). CEN TC 264 is developing a new standard for DAHS. However, DAHS now fall under the scope of the MCERTS scheme for environmental data management software, and the MCERTS performance standards for DAHS are being aligned with the requirements of the future CEN standard. Once the CEN standard is published, we will specify a date after which new DAHS will have to be certified under the MCERTS software scheme.

3 Calibration and validation of the CEM (QAL2)

3.1 QAL2 requirements

QAL2 requires operators to assure that CEMs are installed in the correct location, that there is sufficient access to maintain, assess and control them, and to ensure that CEMs are both calibrated and operating correctly. To this end, EN 14181 specifies two parts to QAL2, which are:

- a set of functional tests and checks to ensure that the CEM has been installed correctly and is functioning at, or better than, the required performance levels. The functional tests are specified in Annex A of EN 14181, whilst this guidance note provides guidance on the functional tests in Annex 1;
- a set of repeated, parallel tests using SRMs to verify whether the sweep of readings from the CEM is reliable, and to derive a calibration function if the SRM data shows that there is a bias in the CEM readings;
- a set of statistical operations and tests following the parallel reference tests, to verify whether the CEMs meet the uncertainty budgets specified in the WID and LCPD;
- calibration using surrogates; if the spread and scatter of the SRM data mean that it is unsuitable to derive a calibration function, then the operator, test laboratory or CEM supplier must calibrate the CEM using alternative means.

3.2 Location of CEMs and sampling ports

3.2.1 Location of the CEM

Operators have to follow the provisions for location and access described in TGN M1⁸ and the MID for EN 15259⁹ in order to determine the most representative location for the CEM, according to the homogeneity test described in EN 15259. Before installing the CEM, the stack gas must be characterised in order to determine whether there are variations across the stack, such that the sampling position will have a significant bias on the readings. It is critical that CEMs are located at a point where there is access and other provisions for the effective and continued operation of the CEM, and also provides a representative sample.

The MID for EN 15259 describes a procedure to determine whether the sample will be representative. This procedure involves taking grid measurements of the stack-gas at centres of equal area across the sampling plane and comparing the results to a fixed reference point within the sampling plane. Additionally, the requirements described in BS EN 13284-1¹⁰ for sampling point locations and provisions for monitoring should also be taken into account, particularly when sampling particulates. Additionally, the CEM must be located at a point where the sample is representative, and the SRM and the CEM (or its sampling location) should be located so that they do not interfere with each other.

3.2.2 Location of the sampling ports

Two international standards describe the requirements for locating sampling ports. These are BS EN 13284-1, which specifies requirements for monitoring low levels of particulate matter, and BS EN 15259, which includes requirements for measurement sites using reference monitoring.

Key point

Spatial variations in temperature, pressure, flow-rate and stack-gas concentration should meet the requirements described in EN 15259. Test laboratories should use the MID for EN 15259 when characterising the stack gas conditions and assessing the intended location of the CEM.

3.3 Management system requirements

EN 14181 requires operators to have a systematic approach to managing and maintaining the CEMs, documented through procedures within an existing management system, such as those meeting the requirements of BS ISO 9001¹¹ or BS EN ISO 14001¹². Operators are also recommended to refer to the requirements of BS ISO 10012¹³ for measurement management systems. Such procedures should include specific provisions for CEMs covering:

- selection
- maintenance and servicing
- responsibilities and training of personnel
- calibration, quality assurance checks and controls
- records and data management
- prevention of unauthorised adjustment of the CEM and its data recording devices
- maintaining availability – spares, contingencies and back-up monitoring.

Key Point

Operators can use management systems based on BS EN ISO 9001, BS EN ISO 14001 or BS ISO 10012 to provide for the management aspects of EN 14181.

3.4 The functional tests

3.4.1 Delegation of responsibilities

EN 14181 requires a set of functional tests to be carried out as part of the QAL2 (there are similar requirements for the AST - see section 5). The functional tests may be performed by the operator, test laboratory, CEMs supplier, or another third-party. However, we specify six requirements for the functional tests:

- The operator is responsible for ensuring that the functional tests take place, typically not more than one month before the parallel reference tests in the QAL2 or AST. Longer intervals may be allowable if the operator can justify this; for example, the operator can demonstrate that there have been no significant changes to the CEMs or process; and that the CEMs have remained stable and under control;
- The test laboratory must notify the operator in advance of the QAL2 or AST, that EN 14181 requires the functional tests;
- The test laboratory must report the results of the functional tests, in section five of the EN14181 report, including all the information detailed in the templates of MID EN 14181;
- Whilst anyone may perform the functional tests, those performing the tests must have demonstrable competence and training to do so; for example, there must be training plans, evidence of assessments and training records to demonstrate that the people performing the functional tests know, understand and can apply the procedures required by Annex A of EN 14181;
- The functional tests must meet the requirements in Annex A of EN 14181, clarified and explained in the MID for EN 14181, and Annex 1 of this TGN;
- If the sampling system is equipped with a NOx converter, then the operator needs to ensure that the efficiency of this converter is tested at least once per year, more frequently if the manufacturer of the converter specifies more frequent checks, and the efficiency must not be less than 95%. The test for converter efficiency should meet the requirements of EN 14792. The test may be performed by any organisation with

demonstrable competence to perform this test. Our preference is that those performing the test should apply gas-phase titration.

3.4.2 Performing the functional tests

The linearity check is specified for the AST but not for the QAL2 test. However, we recommend this test is performed during the QAL2 as well, because EN 14181 permits the use of reference materials to extend the calibration range, subject to certain conditions. The linearity check may provide the necessary data in order to extend the calibration range, or to provide a means of calibration if the spread of data is insufficient to determine a valid calibration function. Historical data is a good indicator of whether the linearity check will be required; for example, if the emissions are typically low, the SRM data may be insufficient to derive a calibration function.

The manual zero and span checks shall be performed using the same procedure as for the MCERTS performance tests. Typically the zero and span checks require the use of reference materials. However, in the case of particulate monitors, these checks will require the use of surrogates for zero and span.

These tests require that:

- each CEM for gaseous compounds have an injection point for calibration gases as close as possible to the sampling point in order to check the response time (functional test described in A.11 of standard EN 14181);
- the output for the raw signal(s) is accessible and useable.

The inevitable downtime incurred in the CEMs through the functional tests need not be subtracted from the annual availability allowance specified in the MCERTS performance specifications, although operators must still comply with the requirements of Article 13(1) of the WID, as specified in the permit.

Key points

- **The process operator shall have overall responsibility for ensuring that the functional checks specified in the QAL2 and AST are performed, but the functional tests may be performed by any party as long as the tests meet the requirements of Annex 1 of EN 14181. Test laboratories are responsible for reporting the results of the functional tests, within QAL2 and AST reports.**
- **Although QAL2 does not require a linearity check, this test is strongly recommended to provide supporting data for calibration.**
- **Historical data can indicate if the test laboratory should perform the linearity test. If the emissions are typically low, then the SRM data may be insufficient to derive a reliable calibration function. Therefore the linearity data should provide an alternative means of calibration.**
- **For extractive systems the CEM shall have an injection point for calibration gases located as close as possible to the sampling point in order to check the response time and determine the valid calibration range.**

3.5 Verification and calibration

3.5.1 Verification and the spread of data

EN 14181 requires SRMs to be used to verify and calibrate CEMs. EN 14181 bases this requirement on generic standard BS ISO 11095¹⁴, which describes how monitoring

equipment is calibrated using a SRM. It is based on three premises for its effectiveness and accuracy. These are:

- there is a spread of data over the required range of the monitoring system;
- there is a linear relationship between the CEM data and the SRM data, when both sets of measurements are valid;
- the SRM is linear, accurate and precise.

Although EN 14181 works best when there is a good spread of data and the CEM has a linear response to increasing values of the target determinand, it is also common for emissions results to be clustered. Therefore the most likely patterns of emissions that test laboratories encounter are:

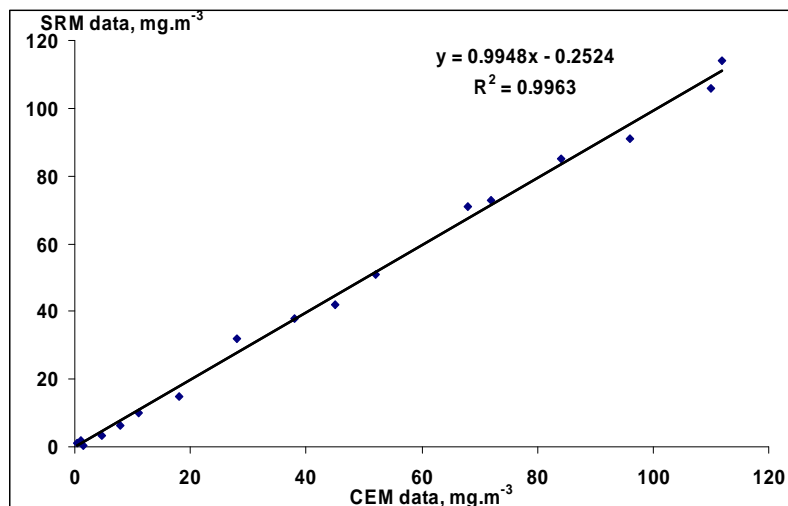
- a linear spread of data across a wide range;
- a high-level cluster, i.e. steady state readings from the CEM, due to stable emissions;
- a low-level cluster, i.e. situations where the emissions are highly controlled and typically close to zero.

A cluster is defined as a set of data whose range of values is not more than 15% of the ELV.

(i) A linear spread of data

Figure 2 shows a set of data with a linear spread. Using this data, the test laboratory can derive the calibration function by using linear regression (Method A on Page 17 of EN 14181).

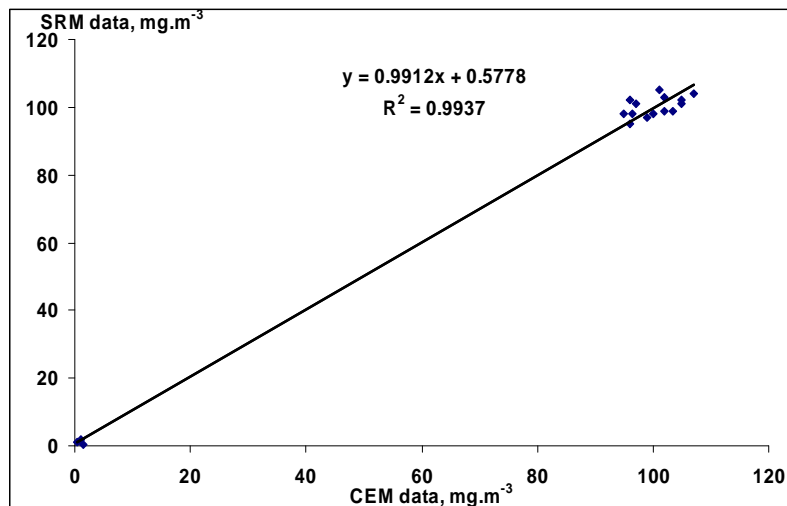
Figure 2 – the principle of linear calibration using a SRM



(ii) A high level cluster

Figure 3 shows a high level cluster. Provided that there is at least one value at or near zero, and that the scatter of the data points is not too large, the test laboratory can determine a calibration function using Method B on Page 17 of EN 14181. EN 14181 requires confirmation that CEMs read zero when the emissions are zero; if the process variations do not provide zero readings, then a surrogate for zero emissions is acceptable, i.e. a zero test gas can be used to generate the readings. Figure 3 shows a high-level cluster.

Figure 3 – A high level cluster

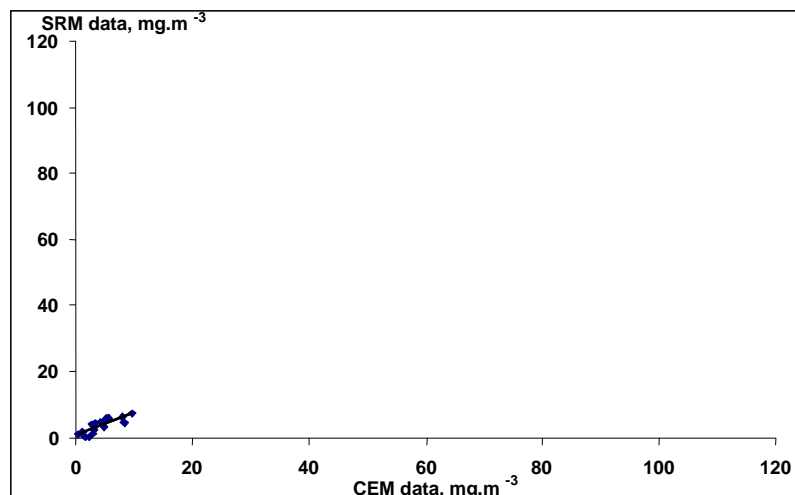


(iii) A low-level cluster

Figure 4 shows a low-level cluster. This is a typical pattern of emissions results when the emissions are highly controlled. In such cases, the calibration function is not reliable unless the cluster is highly linear (as indicated by a correlation coefficient of the regression (R^2) value of 0.9 or more for gaseous compounds or 0.5 for dust); this is because EN 14181 was developed for cases where the emissions are towards the ELV, or at least well above zero. Low-level clusters occur when the emissions are low, where low emissions are defined as those which do not exceed the 95% confidence interval of the daily average ELV.

When the emissions are low, the repetitions of the SRMs are useful to determine if the values from the CEM are in a valid range, but it is better to calibrate the CEMs using surrogates if this is possible. For example, linearity data can be used to calibrate the CEM. In such cases, the reference material should be plotted on the Y-axis, and the CEM data is plotted on the X-axis.

Figure 4 – A low level cluster



3.5.2 Monitoring strategy

The expected spread of data, based on process information and prior monitoring data, will dictate the monitoring strategy. Whilst EN 14181 prescribes at least 15 sets of parallel

measurements over at least three days using SRMs, this depends on there being a linear spread of data over as wide a range as possible. If the results do not fulfil this basic condition, then it is not always possible to carry out all the procedures prescribed in EN 14181. In such cases – especially when there are low levels of clustered data, EN 14181 has more purpose in verifying results, than for calibrating CEMs.

Figure 5 shows the monitoring strategy that can be applied when determining an appropriate approach to monitoring. If the emissions are typically below 30% of the ELV, then EN 13284-2 for particulate-monitoring CEMS allows the number of parallel reference tests for a QAL2 to be reduced from at least 15 to three to five sets of parallel measurements, and for an AST, from at least five, to three to five repetitions. The total time of the measurements should be at least 7.5 hours. However, this may be reduced depending on individual circumstances. For example, three tests of two hours each may be acceptable, if this would reduce the uncertainty of the results. In all such cases, if the test laboratory wishes to conduct tests over a shorter, total time period, then the test laboratory or operator must contact the site regulatory officer in the first instance, justifying the request for reduced sampling.

The premise behind reducing the number of samples, and sampling for longer times, is that when results produce low-level clusters of emissions data, there is a much greater risk of the uncertainty of calibration; small changes in even one or two data points can significantly change the slope of calibration function. This principle can apply to QAL2 tests for gaseous CEMs as well. Further guidance on the spread of data is provided in Section 3.5.11.

3.5.3 Particulate monitors and low level clusters

If there is a low-level cluster for gaseous CEMs, then it is relatively straightforward to calibrate the CEMs using test gases or other surrogates traceable to national standards, such as internal gas cells. However, in the case of particulate monitors, there are no surrogates available which can accurately mimic a CEM's response to specified concentrations of particulate matter. Therefore there are three options available to set up a particulate monitoring CEM for monitoring emissions, if the SRM data is not sufficiently high to calibrate the CEM using the principles of linear regression analysis.

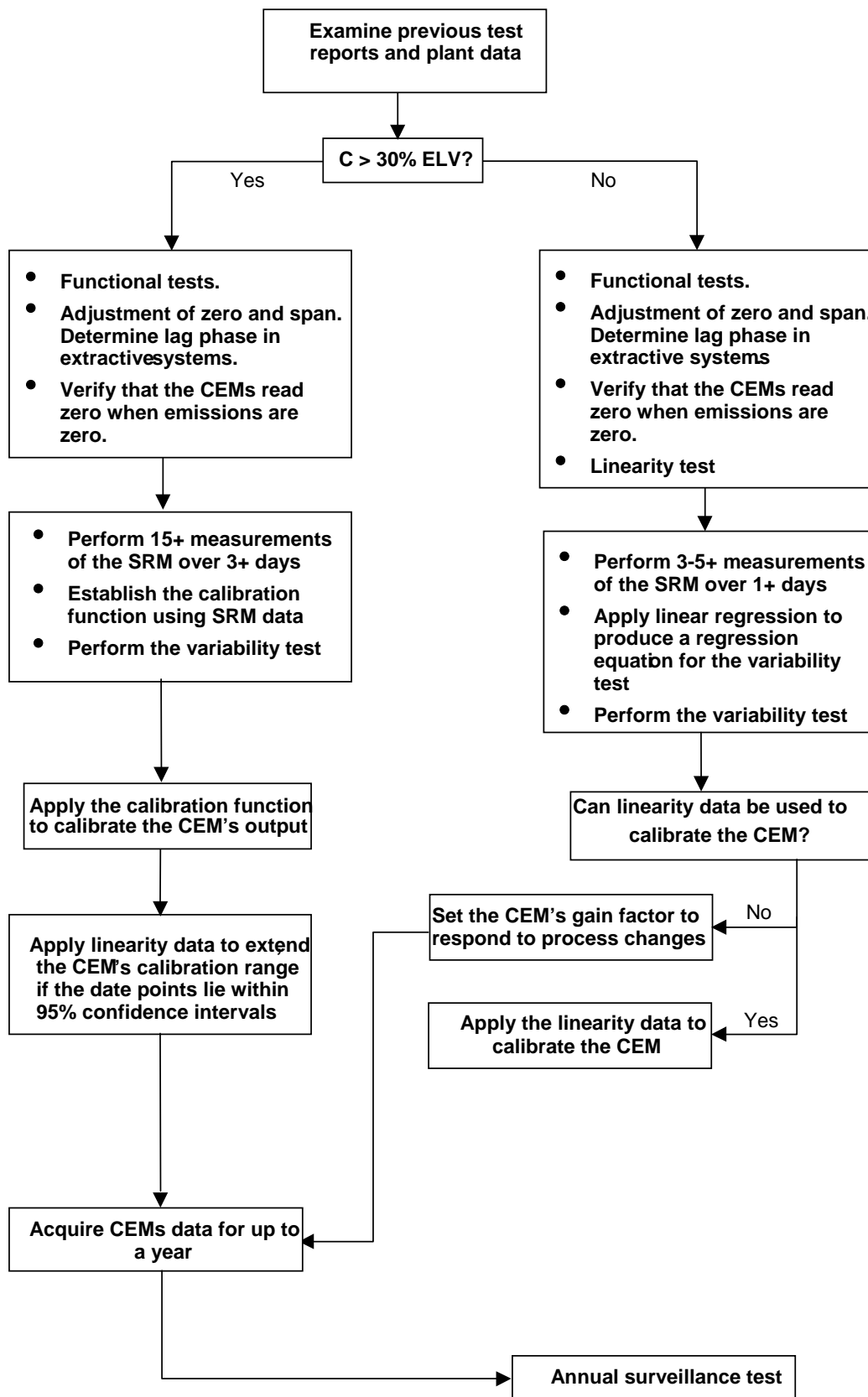
- If the average particulate emissions recorded using the SRM are greater than the uncertainty of the SRM, then use the average value to calibrate the CEM;
- If there is sufficient data available from the site, or from similar sites with higher emissions, then the CEM supplier or test laboratory can calibrate the CEM based on experience and a best estimate of the CEM's response to expected concentrations;
- If there is no data available to calibrate the CEM by the above methods, then the gain setting of the CEM should be adjusted so that small variations are detectable and a significant increase in emissions can be identified immediately; this may correspond to the most sensitive range of the CEM.

In simple terms, if neither SRM data nor surrogates are sufficient to calibrate the CEM, then:

- The purpose of the SRM data is to verify that the emissions are low;
- The CEM becomes a qualitative indicator of significant changes in emissions, rather than a quantitative monitor.

Note: Environment Agency Quick Guide RM-06 provides guidance on calibrating particulate monitors under all conditions.

Figure 5 – Monitoring strategy



Ordinarily tests totalling 7.5 hours would be required. However, this may be reduced depending on circumstances, such as during a batch process. Confirmation should be sought from the site inspector.

Note: The linearity test is mandatory for ASTs, recommended for QAL2s, and essential when the expected emissions are low.

3.5.4 The standard reference methods (SRMs)

Only test laboratories that are accredited to BS EN ISO/IEC 17025 for the MCERTS performance standards for manual stack-emission monitoring for the applicable SRMs may perform the SRM measurements during QAL2 and AST. Additionally, all test laboratories must have EN 14181 within their scope of accreditation, as applied through the MID for EN 14181. However, the test laboratory may be an external third party laboratory or part of the operator's organisation. The applicable SRMs are defined in TGN M2¹⁵.

We recommended that the three days for the QAL2 reference tests should be spaced apart so that the data can be analysed after each day. This is especially relevant for particulates, although dust filters can be weighed on site to plot SRM guide results – the final results obtained after the drying of filters and the addition of rinsings, will be somewhat different but are unlikely to change by more than the 30% confidence interval specified in the Directives. However, if this is impractical, then we recommend that the test laboratory examines the process characteristics and historical data in order to plan the strategy for monitoring.

Key Points

- **Only test laboratories accredited to ISO 17025 for the MCERTS performance standards for manual stack emissions monitoring for the applicable SRMs may perform the reference monitoring tests in QAL2 and the AST.**
- **The SRMs are prescribed in TGN M2.**
- **The SRM data should have a wide spread over the measurement range, a low scatter and show a linear response to an increase in the value of the determinand**
- **The test laboratory may be an external third party laboratory or part of the operator's organisation.**
- **The calibration function within QAL2 and the AST are based on the premise that the SRM is sufficiently accurate and precise, as well as producing an adequate spread of data over the applicable range of the CEM.**

When monitoring CEMs which measure NO_x, the following rules shall apply when performing the SRMs:

- If the operator is permitted to measure NO alone, then the SRMs may also be applied to NO alone;
- If the operator is required to measure total NO_x, then the SRMs must measure total NO_x. The NO and NO₂ may be measured independently or together as total NO_x, as long as the adopted approach is consistent;
- If the operator is permitted to measure NO alone, but chooses to measure total NO_x, then SRMs shall also measure total NO_x. If the operator measures NO and NO₂ independently, then the operator may apply to us for authorisation to change to measuring NO alone, and then reporting total NO_x through the use of a conversion factor;
- When test laboratories use instrumental SRMs to measure NO or total NO_x, the requirements for certification ranges shall apply (see sub-section 3.7).

3.5.5 Prior time-matching of the SRM and CEM data, and data acquisition

The SRM and CEMS may have different response times, which may lead to difficulties in the correlation between their respective data. Therefore the test laboratory shall harmonise the time periods of the measurements between the SRM and CEMS, taking into account the following:

- The lag time of the gas sampled in the lines, i.e. the time between sampling and analysis. The transfer times in the CEMS and SRM lines are calculated taking into account the lengths of the lines, their geometry and the incoming flow;
- The clocks of the SRM and CEM methods must be synchronized and a correction equal to the difference in the transfer times between that of the CEM and that of the SRM must be made to correlate the results;
- The frequency of data acquisition;
- Analyser response times;
- When conducting the parallel measurements with the SRMs, the test laboratory shall either take the signals measured directly by the CEM, or data from the site's data collection system.

3.5.6 Calibration using a SRM

Figure 6 illustrates the principle of linear calibration using a SRM in which the SRM data is compared with the CEM data and is used to derive a calibration function. The CEM itself may have a bias in one direction or another, depending on gain of the CEM and its offset relative to zero. A calibration function, in its simplest form, can then be described by equation (1):

$$y_i = bx_i + a + \varepsilon \quad (1)$$

where:

y = the SRM values for i = 1 to n

x = the CEM values for i = 1 to n

b = the slope of the calibration function

a = the intercept of the calibration function

ε = the deviation between the actual and the expected value

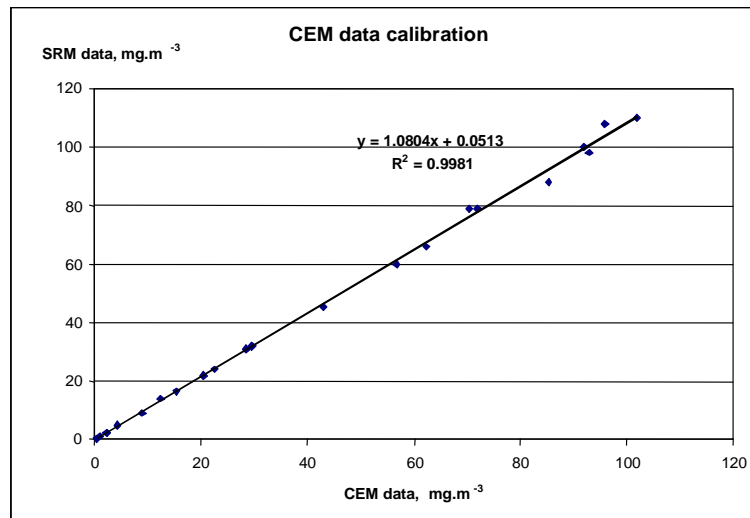
It is unlikely that the SRM will produce a perfect straight line with no scatter when monitoring stack emissions. However, it is essential that the scatter - or imprecision - of the SRM is less than that of the CEM being calibrated and validated. Therefore the test-laboratory must characterise the SRM thoroughly and assure that the uncertainties are not only well known and understood, but also well below the uncertainties specified in the WID and LCPD (ideally, no more than half the uncertainties specified in the WID and LCPD.) If these conditions are not fulfilled, then EN 14181 will not be an effective tool for calibration of the CEM. In a worst case, it may either fail or mis-calibrate a CEM due to deficiencies within the SRM application, rather than any faults or a lack of accuracy and precision within the CEM itself.

Generally equation 1 can be simplified to:

$$y_i = bx_i + a$$

This is because the deviation between the actual and expected value is usually insignificant when compared to the offset (if applicable). In the case of high level clusters, the approach differs in that Method B calculates an average of the data cluster and then forces the calibration line from the average of the cluster through zero.

Figure 6 –the principle of linear calibration using a SRM



3.5.7 Instrumental SRMs

Test laboratories may use SRMs that are based on either manual methods or instrumental methods. The following two conditions shall be met if a test laboratory wishes to use instrumental SRMs:

- The test method using the instrumental technique shall either be an SRM or an alternative method (AM). To check equivalence of alternative methods to SRMs, refer to BS EN TS 14793¹⁷ and TGN M2 ;
- The monitoring equipment used shall either be MCERTS certified for all the applicable determinands and the appropriate ranges or the test laboratory must have alternative test data from an accredited test facility which demonstrates that all the instrumental systems also meet the MCERTS performance standards.

MCERTS certification - or equivalent data demonstrating compliance with the MCERTS performance standards - is critical, since any instruments used to calibrate and validate CEMs must meet at least the same performance standards as the CEMs being calibrated and verified. The ranges of the MCERTS certification are especially important, so that the instrumental system used within the SRM has an uncertainty that is at least as low as the uncertainty that the CEM has to meet. Monitoring systems used within SRMs shall also undergo appropriate quality control and assurance checks specified within the applicable standards at least annually and preferably more frequently. Standards such as BS EN 14792¹⁸ include such provisions for quality control and quality assurance.

Key Points

- **If instrumental techniques are used within SRMs, then the monitoring systems used shall either be certified to the MCERTS performance standards for the applicable determinands and appropriate ranges, or the test laboratory must be able to provide other equivalent evidence that each of the instrumental systems meets the MCERTS performance standards**
- **Monitoring systems used within SRMs shall undergo appropriate quality control and assurance checks at least annually and preferably more frequently, as defined in applicable standards.**

3.5.8 The acquisition of data

When conducting the parallel measurements, EN 14181 requires the test laboratory to take the measured signals directly from the CEM (e.g. expressed as an analogue or digital signal) during the QAL2 and AST tests, using a recording system that takes frequent samples in relation to the response time of the CEM. However, if this is not practicable, then the test laboratory may take the data from a different output, such as the data recording system in use at the installation – provided that there is evidence to show that the data matches the output from the CEM. This can be obtained, for example, by observing the display of the CEM at the same time as the display of the installation's data recording system, taking into account the units applied to the data.

3.5.9 Spread of data and modes of operation

The test laboratory must select a set of representative operating conditions that cover as wide a range as possible, but deliberately modifying the process to artificially increase emissions is not permitted. Ideally operators should select a time when the emissions are likely to be their highest and most varied, but the process may not be deliberately varied in order to create higher than normal emissions. For example, when bag filters are replaced, emissions of particulate are temporarily higher and this produces an ideal time to measure a wider range of emissions.

The WID and LCPD set ELVs which apply to normal operations. This means that start-up and shutdown are excluded. However, it is not always a simple exercise to determine the boundaries for these modes of operation. This can cause divide-by-zero errors when oxygen concentrations increase. Therefore the operators of some installations such as incinerators have agreed a threshold oxygen concentration to determine when a process is under normal operation; the value of oxygen is typically 18%. If the boundary conditions for start-up, shutdown and normal operations are not clearly defined, then consult the local inspector or a member of the our Operator Self-Monitoring Team for guidance.

3.5.10 Averaging periods for SRMs

The averaging period for each SRM measurement should be equal to the averaging period of the short-term ELV; this ordinarily means 30 minutes for WID installations, and 60 minutes for LCPD installations. Test laboratories should consider longer averaging periods if the emissions are low. Test laboratories may use averaging periods of less than 60 minutes for LCPD applications if the test laboratory can demonstrate that there is no significant difference between 30 minute and 60 minute averaging periods. However, the averaging period must never fall below 30 minutes.

3.5.11 Number of data points and outliers

(i) Number of repetitions

QAL2 specifies at least fifteen sets of valid data when performing the SRMs and it is advisable to obtain at least 18 or 19 sets of data to ensure sufficient valid data sets. There must also be data at zero, or near zero, where near zero is defined as a value that is no more than 5% of the ELV. Ideally zero values should be measured when the installation is not producing emissions and if this is not possible, then the test laboratory may use surrogate values.

Note: It is often better to use surrogates at the zero point. Although the EN14181 analysis assumes that the SRM measurement is perfect, the uncertainty in the SRM reading may be higher than the CEM when close to the zero point. This is especially the case for dust – even though some fine dust is present when the plant is off (due to the chimney draught entraining loose material) – the gravimetric test uncertainty is high - which can result in a false zero offset. This suggests that surrogates should be used as a matter of routine.

Figure 7 shows an adequate spread of data and Figure 8 illustrates the impact of an insufficient spread of data. In Figure 7, there are values near zero and the R^2 value for the linear regression line is an acceptable value of approximately $R^2 = 0.9$. However, if all the values are clustered (Figure 8), then the linear regression line – and hence the calibration function – is very different, and the R^2 value is unacceptably low (about 0.1). A similar case arises when the data is clustered too near to zero (Figure 4) and when there is not a sufficient spread of data across the measurement range.

The QAL2 and AST tests must provide at least fifteen and five sets of data respectively. The data should ideally be spread over at least 50% of the ELV with at least one data point at, or near, zero. Indeed, when describing the procedure for dealing with clusters of data well above zero, EN 14181 requires the test laboratory to verify that the CEMs read zero when the emissions are zero. This is not just to check that the CEMs read zero when there are no emissions to record, but because the procedure involves taking the mean average value of the cluster of data, and then forcing the calibration line through the average zero and the average clustered value.

Ideally operators should select a time when the emissions are likely to be their highest and most varied; for example, when bag filters are replaced, emissions of particulate are temporarily higher for a short time and this produces an ideal time to measure a wider spread of emissions. However, an industrial process may not be deliberately varied outside normal operational conditions, in order to create higher than normal emissions.

If the test laboratory is using instrumental methods for SRMs, then the SRM monitoring-system may be operated continuously over the three days of the QAL2. Zero and span checks on monitoring systems used within SRMs shall take at least at the start and the end of the monitoring period, and at least once every 24 hours. Test laboratories shall state in their Site Specific Protocol the time intervals between the start-time of each pair of measurements. Furthermore, test laboratories shall demonstrate that the interval between each pair of data provides representative samples, taking into account any process variations.

Note: For example, due to process and/or safety constraints, a test laboratory may only be able to take data at certain times. This may occur during a batch process. In such cases, the test laboratory may leave an instrumental SRM running, but still perform the zero and span checks once every 24 hours. In such cases, it is essential to ensure that the measurements are still representative, and that the SRM is stable over a 24 hour-period.

(ii) Outliers

The emphasis is also on *valid sets of data* which cover the ELV – therefore the test laboratory is advised to carry out a greater number of tests in order to meet the minimum requirement. If practicable, the data from the CEM and SRMs should be plotted on a chart as the QAL2 and AST tests progress, as this will indicate whether the spread of data is sufficient, whether the data has enough values near zero and whether there are any obvious outliers.

Test laboratories also need to have a procedure to determine if there are outliers in the data. This procedure shall be based on Quick Guide RM-14, which provides guidance on dealing with outliers. As a general guide, when plotting the raw SRM and raw CEM data, if the R^2 value for the linear-regression line is equal or more than 0.9, then it is not ordinarily necessary to perform an outlier test. Additionally, any data points are not likely to be outliers unless they are more than two standard deviations from the regression line. The outlier test need only be performed once.

If the test house assesses that a data set is considered invalid then the reasons for this should be noted in the QAL 2 report (for example: changing process conditions, error in SRM, failure of instrument).

Figure 7 – An example of an adequate spread of data for a set of QAL2 measurements

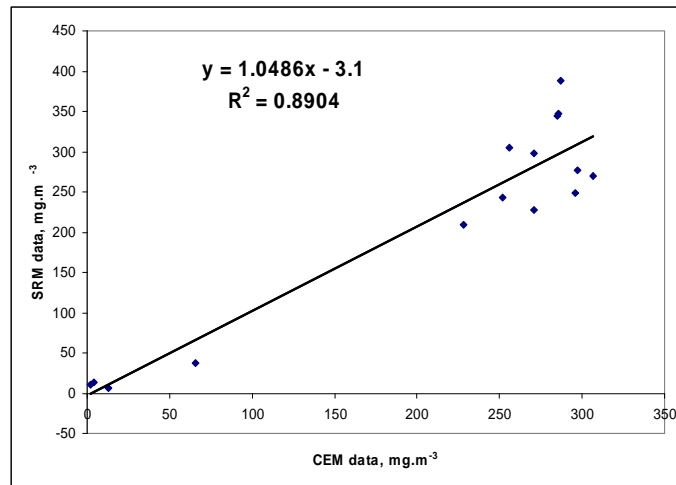
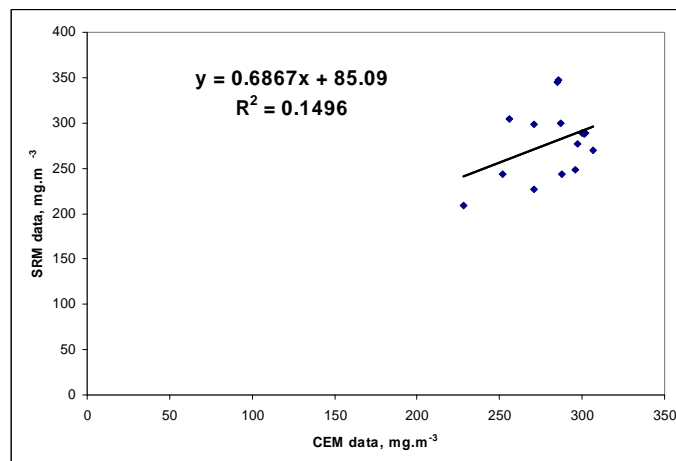


Figure 8 – An example of a set of QAL2 measurements with no measurements near zero



Key Points – Spread of Data

- The QAL2 and AST tests must ordinarily provide at least fifteen and at least five sets of data respectively.
- The data should ideally be spread over at least 50% of the ELV with at least one data point at or near zero.
- The test laboratory must demonstrate that the CEMs read zero when the determinand value is zero.

3.5.12 Method A, Method B or Method C?

ISO 11095 relies on the premise that a set of data will be linear and have a sufficient spread over the measurement range. EN 14181 defines this spread in terms of percentages of the ELV; this standard defines two situations based on the extent of the spread, and then specifies a mathematical method which allows the test laboratory to calculate the calibration

function. These two mathematical methods are defined in EN 14181 as Method A and Method B respectively.

In order to determine whether to use Method A or Method B, the test laboratory uses the SRM data, and must first convert this data to values at standard conditions.

- **Method A:** If the spread of SRM data - i.e. from the largest SRM value to the smallest SRM value - spans at least 15% of the ELV, then the test laboratory uses Method A. This method is a standard linear regression. Even if the spread of data spans more than 15% of the ELV, we still require at least one value near zero, in order to demonstrate that the CEMs read zero or near zero when the emissions are zero, and to estimate the best-fit value of the calibration-line intercept.
- **Method B:** If the spread of SRM data spans less than 15% of the ELV, then the test laboratory uses Method B. In simple terms, this method takes an average of the clustered data points, and then forces the regression line through zero. In order to justify this, the test laboratory must verify that the CEMs read zero or near zero when the emissions are zero.
- **Method C:** EN 14181 was not designed for dealing with low-level clusters, where the calibration function can be unreliable. In such cases, a third method, known as Method C, can be used.

3.5.13 Method C for low-level clusters

A low-level cluster occurs when the emissions do not exceed the 95% confidence interval of the daily average ELV. In such cases, a calibration function according to EN 14181 can be unreliable, as the uncertainties of both the CEM and SRM can unduly influence the calibration function and result in a significant bias in the CEM measurements, as the emissions increase. In such cases, an alternative procedure, known as Method C, can be used:

- The test laboratory can examine the historical results, and if the expected emissions are likely to be low-level clusters as defined above, then either the test laboratory or operator shall contact us for agreement to reduce the number of SRM measurements. If the installation is new, then at least 15+ repetitions will be required, to thoroughly characterise the plant emissions and effectiveness of the emissions-abatement systems.
- Depending on the concentrations and determinand, between 3 and 5 SRM measurements may be performed, for both an AST and QAL2;
- The SRM measurements are used to verify that the CEMs respond to even low concentrations of the determinand. The difference between the average of the SRM and CEM results should not differ by more than half the allowance 95% confidence interval of the daily average ELV;
- The CEMs may be calibrated using surrogates. Gases used for calibration when applying Method C shall be from accredited suppliers; the uncertainty of a calibration gas, including the uncertainty of any gas blender used, shall not be more than 2% for all gases. Gases for QAL3 and functional tests, other than when applying Method C, need not be accredited. Further guidance on gases is given in Sections 3.9.3 and 4.2.1 (for QAL3).

Note: When calibrating particulate monitors, refer to Quick Guide RM-06.

3.5.14 QAL 2 for particulate CEMs

The following provisions apply to the calibration of particulate CEMs:

- The calibration function may be linearised according to BS EN 13284-2;
- The error associated with the SRM increases significantly when the dust concentration is below 5 mg.m^{-3} . Great caution should be applied when making a QAL2 assessment on processes with dust levels lower than 5 mg.m^{-3} ;
- In processes with dynamic dust levels (associated with the cleaning cycle of arrestment plant) the response time of the instrument should be reduced during the QAL2 procedure to permit the instrument to accurately follow these dynamics;
- It is beneficial to conduct the QAL2 on non-consecutive days so that the validity and spread of data from one day's testing can be considered before further testing is conducted.

3.5.15 Peripheral CEM measurements

EN 14181 specifies requirements for *peripheral measurements*. These are determinands which need to be measured but do not have performance characteristics assigned to them within the WID and LCPD. In EN 14181, peripheral measurements are:

- oxygen
- moisture
- temperature
- stack gas pressure

CEMs for oxygen and moisture (if used) must be certified to MCERTS performance standards. The same applies to SRMs that use instrumental techniques. Functional checks should be performed on CEMs for oxygen and moisture (if used) although ordinarily a full QAL2 should not be needed for the installation's peripheral measurements. However, if the CEM fails the QAL2 tests using the operator's peripheral measurements, then the SRM peripheral measurements may be used instead. If the CEM then passes the QAL2 tests, then the operator must fix the peripheral monitoring equipment as soon as possible and verify its performance through QAL2 exercises.

When carrying out the QAL2 exercise, it is recommended that the test laboratory plots a graph of the SRM data versus the CEM data for the peripheral measurements.

SRM monitoring for oxygen is required in any event for the QAL2 tests for other determinands, so the 15+ sets of oxygen SRM measurements can then be used to perform a QAL2 for oxygen. When performing the variability test for oxygen and moisture measurements, the following virtual ELVs and uncertainty allowances shall be applied:

- oxygen: ELV = 21%, 95% CI = 10%
- moisture: ELV = 30%, 95% CI = 30%

If CEM readings for moisture are also found to be erroneous when compared to the reference monitoring and following the variability tests, then the SRM results for moisture shall also be used to perform a full QAL2 exercise on the installation's CEMs which measure moisture.

CEMs for temperature and pressure shall be cross-calibrated using reference instruments that are traceable to national standards.

Key Points – Peripheral Measurements

- CEMs used to measure O₂ and H₂O shall be certified. Measurement uncertainty shall not exceed 10% and 30% respectively on the concentration range covered
- If the CEM fails the QAL2 tests using the operator's peripheral measurements for moisture and oxygen, then the SRM peripheral measurements may be used instead. If the CEM then passes the QAL2 tests, then the operator must fix the peripheral monitoring equipment as soon as possible and verify its performance through QAL2 exercises.
- CEMs for temperature and pressure shall be cross-calibrated using reference instruments that are traceable to national standards.
- Test laboratories must ensure that they perform reference monitoring for peripheral measurements, unless there is a good reason to omit any such measurements.

3.5.16 Sample lines and delays

If the test laboratory uses instrumental techniques within SRMs, then differences between the sampling systems of the CEMs and SRMs can result in a difference in integration time, meaning that sets of measurements starting and ending at the same time may be uncoordinated. Therefore the test laboratory should carry out the following:

- establish if there is a difference in integration time; for example, by injecting a test gas into the CEM and SRM sampling probes at the same time and determining if there is a significant difference in responses, taking into account performance characteristics;
- if this test shows that there is a difference in integration time, then any SRM systems may be connected at the same point on the sampling system as the CEM, in order to align the lag times between sampling and analysis. If this is not practicable, then the test laboratory must measure the differences in lag times and correct the data accordingly;
- alternatively if both the SRM and CEM data have been recorded electronically the data can be aligned afterwards by matching the peaks and troughs.

3.5.17 Establishing the calibration function and the test of variability

In carrying out the analysis of data the following steps are required:

- Tabulate the CEM and SRM data;
- Express the raw SRM data in the same conditions as the CEM data (i.e. either dry or humid, to the same temperature and pressure);
- Plot the CEM data and SRM data together;
- Assess whether there are any outliers using the procedure in Quick Guide 14 and eliminate these; for example, if the CEM undergoes a regular zero and span operation, then such data will be invalid;
- Calculate the calibration function. As guidance, an indicator for a valid calibration function is a correlation coefficient of the regression line of $R^2 = 0.9$ or more, for Method A. However, this guideline may not work for lower level emissions, where the uncertainty can result in more apparent scatter. Hence an R^2 of less than 0.9 does not necessarily indicate a QAL2 failure when the emissions are low – this is often the case with Method B. The variability test should always be considered as the definitive test;

- Establish the valid calibration range (which should cover the ELV);
- Convert the data to calibrated and standardised values;
- Carry out the variability test;
- If the difference between the standardised CEM values (before applying the calibration function) and the standardised SRM measurements do not differ by more than half of the allowable 95% confidence interval of the daily average ELV, then it may not be necessary to apply the calibration function. This is because the differences between the SRM and CEM results can be attributed to the uncertainty of the SRM and CEM measurements. If such cases occur, then it is advisable to contact the local site inspector for approval for this approach.

Note 1: Annex 2 provides additional k_v values when there are fewer than five pairs of data, or more than 15.

Note 2: If the operator and/or regulator requires a QAL2 and variability test for ammonia, then the test laboratory is to use a virtual daily-average ELV of 10 mg.m^{-3} and a 95% confidence interval of 40%, i.e. requirements which are equivalent to those of HCl. Note that there is not yet an ELV for ammonia within legislation.

3.5.18 Scatter of data points

If the emissions are not more than 30% of the daily ELV and the scatter of data points means that it is not possible to derive a valid calibration function, then:

- the CEM may be calibrated using reference materials and Method C.

If the CEMs measure gases, then the CEM may be calibrated using test gases. These gases should have an uncertainty which is as low as practicably possible, i.e. an expanded uncertainty not greater than 2%. If a gas blending system is used, then the combined uncertainty of the blender and test gas shall not exceed 2%.

Note: Details of Method C are described in Section 3.5.12

3.5.19 Spare, repaired or replaced CEMS

There will be situations when a CEM is replaced either temporarily or permanently with a new CEM. The following provisions apply in such cases:

- If the CEM is a hot-standby system mounted on the same stack as the primary, permanent system, then the CEM may either be (i) verified and calibrated at the same time as the primary CEM during the QAL2, (ii) verified and cross-calibrated over a period of at least three days using the calibrated CEM;
- If the operator replaces a CEM with an identical one, then the operator may use the same calibration function as the original CEM, and then verify the performance using an AST. If needed, then the AST may be extended to become a full QAL2;
- If the operator replaces the CEM with a different type of CEM, then this replacement must either undergo a full QAL2, or only the functional tests supported by cross-calibration using a verified and calibrated CEM. This entails using data from the verified CEM;
- If the operator uses a portable monitoring system for back-up purposes, then this portable system should either have a QAL2 for each stack on which it operates, or may be cross-calibrated using permanently installed CEMs on the stack, providing that these have been verified and calibrated.

After repairs, or when replacing a CEM with an identical system, the following procedure is recommended:

- It is recommended that the same quality of test gases are used when setting up the repaired or replacement CEM, after which the operator should apply the same calibration function as before, and then continue with the QAL3 procedure;
- If there are no visible step changes in either the measured emissions when the process has not changed, and if the QAL3 baselines do not change, then no further action is needed;
- If there are visible step changes, then the parallel reference tests for an AST are required. If the repaired or replacement CEM passes both the variability and acceptance tests, then no further action is required;
- If the repaired or replacement CEM fails one or both of these tests, then a QAL2 is required.

3.5.20 Cross-calibrating back-up CEMs

If a CEM has been calibrated and its performance has been verified, then this CEM may be used to cross-check a back-up CEM placed on the same stack. In simple terms, the operator uses the measurements from the verified CEM to cross-check – and if necessary, calibrate – the measurements, for example, from a back-up CEM which is to be used at required intervals on the same stack. In simple terms, an operator uses the calibrated and verified CEM *in lieu* of measurements from an SRM. A procedure for cross-calibration should involve the following steps:

- perform the functional tests as specified in QAL2;
- use the same test gases to initially calibrate the CEM, and to perform the zero and span tests;
- ensure that the sampling ports are close enough to sample representatively for both CEMs;
- operate the primary CEM and the secondary CEM together on the same stack for at least three days;
- use sets of parallel data as specified in QAL2 to calculate the calibration function and to perform the variability test. This should result in a calibration function for the second CEM;
- if the CEM passes the variability test, and the results from both CEMs do not differ by more than half the uncertainty allowance specified by the applicable Directive, then the calibration of the second CEM is regarded as valid, without the need to apply a calibration function. This is because the results would be statistically the same;
- as an additional means of quality assurance, it is recommended that the results from the CEM and back-up CEM are examined using the procedure for assessing reproducibility, as defined in Section 12.7 of BS EN 15267-3.

3.6 Frequency of QAL2 checks

QAL2 tests shall be performed:

- at least every five years for LCPD installations
- at least every three years for WID installations
- if a QAL3 evaluation or AST demonstrates a need for a QAL2

- if there is a significant change to the CEM
- if there is a change of fuel, as defined in section 3.8
- if there is a significant change of process, as defined in section 3.8
- if any of the above changes alter the emissions.

For example, if a CEM fails the acceptance test during an AST, then this implies that a full QAL2 is required. Similarly, if there is a replacement CEM, and following installation and commission, there appears to be a step-change in both the measured emissions and QAL3 baselines for span gases, then this also suggests that a QAL2 is required. However, in the first instance, it is acceptable to perform the parallel reference tests required by an AST, before performing a QAL2, using the existing calibration function. If there are passes for both the variability tests and acceptance tests, then no further action is needed.

3.7 Performing an AST instead of a QAL2

Following the first QAL2, an AST may be performed instead of a subsequent QAL2 if:

- daily average gaseous emissions are less than 50% of the ELV in-between QAL2 exercises;
- daily average particulate emissions are less than 30% of the ELV in-between QAL2 exercises;
- there is no significant change to plant operation or fuel.

Note: This means that after an initial QAL2, we may allow ASTs during the following years, instead of a QAL2 every three years under the WID, or five years under the LCPD.

3.8 Significant changes to operating conditions and fuels

An operational change is considered significant if it triggers the need for a permit variation and the change alters the emissions.

A change of fuel is considered significant if:

- it results in a change in the emissions profile;
- it requires a permit variation and alters emissions;
- the change is from any one of the following types to another – gaseous fuel, liquid fuel, solid fuel - and the alternative fuel is used for more than 10% of the time during a year;
- the change is from a single type of fuel to a mixture of more than one type of fuel (or vice versa), and the alternative fuel (or mixture) is used for more than 10% of the time during a year.

However, a new QAL2 for changes in the process or fuel will not be needed if:

- the operator can demonstrate that the change in process does not affect the emissions profile and the original calibration factor remains valid;
- the thermal input is less than 10% per year for the alternative fuel, and/or;

- the change in fuel use can be shown to have no significant effects on emissions, when compared to the original fuel.

If there is a change of fuel, then the operator should first perform an AST (refer to section 8 in EN 14181.) If the results fit within the 95% CIs of the calibration range, then no further testing is required. If not, then a full QAL2 is required.

3.9 Extending the calibrating range

This section covers two cases; when it is possible to select a time for sampling which produces representative data up to the highest typical values, and when it is not possible to select an ideal time for representative sampling.

3.9.1 When it is possible to choose an ideal time for representative sampling

In order to produce an ideal, valid calibration range, the monitoring using SRMs would be performed when the emissions are representative of the process and captures the typically highest emissions.

SRM data provides the valid calibration-range. EN 14181 defines the valid calibration-range as the maximum value of the calibrated CEM data, plus an allowance of 10%. Additionally, the valid calibration-range may be extrapolated to the ELV in order to show that any readings beyond the calibration are most likely valid. The range is extrapolated by using a test-gas at the ELV. The CEM reading for the test-gas must lie within the 95% confidence interval of the ELV, as defined by the applicable EC Directives (Figure 9).

If the emissions exceed the valid calibration range derived from SRM data, but within the extrapolated range, then ordinarily the provisions of section 6.5 of EN 14181 apply. These state that a new QAL2 is required if:

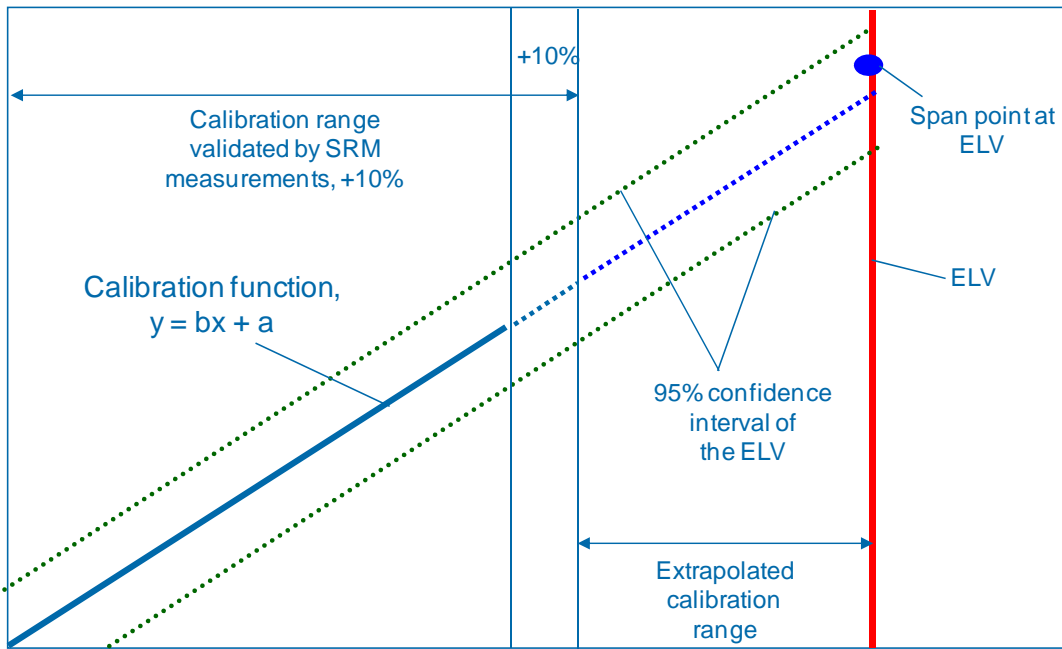
- more than 5% of the number of measured values from the CEM, calculated weekly, are above the maximum calibrated CEM value (+10%) for more than five weeks in the period between two AST or QAL2 tests;
- more than 40% of the number of measured values from the CEM, calculated weekly, are above the maximum calibrated CEM value (+10%) for more than one week in the period between two AST or QAL2 tests.

If these criteria cannot be met, then this suggests that at least one of the following has happened:

- the original QAL2 exercise was carried out when the emissions were not representative;
- the process has changed.

Whether one or both of these conditions apply, a repeat QAL2 is required.

Figure 9 – Extrapolating the valid calibration range, when process peaks are predictable



3.9.2 When it is not possible to choose an ideal time for representative sampling

In situations where the normal process variability makes it impractical to obtain a sufficiently high valid calibration range, using this approach, the valid calibration range can be extended to 2x ELV using surrogates, provided that the level of agreement between linearity data and the QAL2 calibration line is within the confidence interval specified in the relevant European Directive, and this approach has been agreed between an industry sector and us. The linearity data should be plotted on the above QAL2 graph and the agreement at all points should be within the 95% confidence interval at the ELV. We must emphasise, however, that this approach can only be adopted by an industry sector if it has our agreement. Additional confidence in this approach can be demonstrated by reviewing historic AST data.

Note: Currently the above approach has been agreed between us and the coal-fired power-sector.

It is good practice for the test laboratory to check the level of agreement between the SRM and the AMS at the span value during the functional checks, taking into account the certified uncertainty of the span gas. If there is a difference of more than half of the confidence interval at the ELV, then further investigation is warranted. When plotting linearity data on the QAL2 graph, the test laboratory should enter the expected concentration level as the SRM data.

3.9.3 Requirements for test gases

Test laboratories must use traceable gas standards for QAL2 and AST testing, noting that functional checks may be conducted using the operator's site gases. Traceable gas standards are prepared under ISO 17025 accreditation to better than $\pm 2\%$ uncertainty at 95% confidence. There is then an auditable chain of direct measurements linking the concentration of the test gas back to a Primary Standard Gas Mixture, produced by a National Measurement Institute, and ultimately to SI units. These gases are referred to as ISO 17025 Accredited Gas Standards (AGS) and also Certified Reference Gas Mixtures. The analytical result is stated on the Calibration Certificate with a calculated measurement uncertainty.

However, it should be noted that ISO 17025 accreditation is limited to binary mixtures of one gas component in nitrogen. The available gases and concentration ranges vary between suppliers and accreditation is not widely available for nitrogen dioxide. ISO 17025 AGS do not have a specified stability period, noting that the test laboratory is expected to submit the AGS for re-certification periodically in accordance with the supplier's recommendations. Under the scope of UKAS accreditation, the test laboratory is also permitted to use a transferable gas standard on site, i.e., the test gases are cross-compared with the AGS beforehand. ISO 17025 AGS lead times are generally longer than three months.

Operators usually use multi-component Working Gas Mixture Standards (WGMS) for QAL3 drift checking, with a concentration tolerance of $\pm 2\%$, in order to minimise the required number of gas cylinders for reasons of safety, practicality and cost. Certificates of Analysis are prepared in accordance to ISO 6141:2000. These gases may also be used for occasional adjustment of the instrument provided that the CEM manufacturer accepts the gas mixture as being generally suitable for adjustment purposes. Adjustment may be required following a QAL3 failure or when the instruments are serviced as discussed below. The use of WGMS reduces the overall burden on the operator since two sets of gas cylinders do not need to be held on site. This practice also reduces the time required for conducting QAL3 tests. WGMS are available with a short delivery of typically two weeks and have a declared stability period, ranging from six months to three years, after which they must be replaced. It should be recognised that preparation of WGMS is generally to a high quality, using gravimetric standards and proven analytical procedures.

If binary gas mixtures are required by the CEM manufacturer for instrument adjustment, the operator may elect to use the same set of binary gases for QAL3 purposes. ISO 17025 AGS are preferred under these circumstances, if these are available for the required gas components and concentration ranges.

If the site gases are not accredited, it is recommended that the test laboratory checks the site gases using ISO 17025 AGS, although it is acknowledged and accepted that this procedure is unlikely to be within the scope of accreditation of the test laboratory. This can be achieved by passing the site gas through the test instruments that have been adjusted using the AGS. The required level of agreement must be within the combined uncertainty of the site and test gases; for example, an uncertainty of 2% for both the site and test gas would require agreement within 2.8%. If there is poor agreement, the test laboratory should report this and decide on the best course of action with the operator. For example, there may be sufficiently close agreement for QAL2/AST purposes and the quality of the site gas can be investigated at a later stage. However, if the QAL2/AST is jeopardised then the CEMs may need to be adjusted using the test laboratory AGS and a new site gas ordered.

Table 3 - Requirements for test gases

Activity	Gas requirement	Subject to
QAL1 certification		EN 15267-3
Bench testing	AGS	ISO 17025
Field trial	AGS	ISO 17025
QAL2/AST (on-site validation)		EN 14181
Initial CEM set-up on site	WGMS ¹	ISO 6142 ² and ISO 17025
Functional checks	WGMS	ISO 6142 ² and ISO 17025
Linearity test for Method C	AGS	ISO 17025
Site-gas quality check	AGS	ISO 17025
Test laboratory instruments	AGS	ISO 17025
QAL3 (drift checks)		EN 14181
Zero check	Zero-grade N ₂ or clean air	Impurity analysis if needed ³
Span check	WGMS ¹	ISO 6142 ²
Adjustment (if required)	WGMS ¹	ISO 6142 ²

Note 1: AGS can always be used in place of WGMS. AGS is recommended for the initial calibration of the CEM following installation or major servicing.

Note 2: Reactive gases must also be traceable analytically to National or International standards

Note 3: To suit CEM requirements (traceable analytically to National or International standards)

Note 4: The above requirements have been agreed with JEP and written by JEP.

3.9.4 Requirements for test QAL2 and AST test-reports

Test reports shall comply with the requirements of the MID for EN 14181, specifically the contents and structure specified in Appendix 2 of this MID.

4 Ongoing quality assurance during operations (QAL3)

4.1 QAL3 - general

4.1.1 Background

The purpose of QAL3 is to detect drift and changes in precision in the CEM by performing regular checks of the zero and span readings. These may be checked using reference materials or using a surrogate method traceable to national standards.

The principle behind QAL3 is that operators should track the stability performance of the CEMs, and not make any adjustments unless necessary. This is because the zero and span readings on a CEM will typically undergo minor changes due to influence factors such as changes in temperature and pressure. Due to such variations, the CEMs may appear to drift but are not; whilst there may be no harm in making small changes to the setting of the CEM in response to this apparent drift behaviour, it is preferable that the operator does not make any adjustments unless the CEM really has drifted. Control charts allow an operator to detect when these changes are due to chance or influence factors, and when the CEM really is drifting. So to help with this procedure, EN 14181 prescribes using control charts.

The operator may use any type of control chart, ranging from simple plots of zero and span drift, through to complex types such as exponentially weighted moving-average plots, and CUSUM charts. When using a control chart, the user determines levels of drift which will trigger action; typically there is a warning level, and an action level. These allowable variations expressed as standard deviations, or s_{AMS} in EN 14181. The warning and action levels are expressed as multiples of s_{AMS} . An initial QAL3 check is required before starting to report data. Any changes in drift are then compared to the MCERTS performance specification for the applicable certified range of the CEM to decide if any intervention is required e.g. maintenance of the CEM.

4.1.2 Determining s_{AMS}

The s_{AMS} can either be calculated using MCERTS test data, approximated based on the ELV multiplied by a factor, or determined by using span test gases. Then multiples of s_{AMS} are used to set warning levels and alarm levels.

When calculating s_{AMS} , use the method described in the examples in EN 14181 for determining s_{AMS} , but we recommend using the following influence factors:

- effect of ambient temperature
- effect of stack gas pressure for in situ CEMs
- effect of voltage

- cross-sensitivity to other determinands
- detection limit.

When using test gases, several readings are taken and the standard deviation is calculated from these readings. This approach is simple and practical, but if the operating conditions at the time result in a high precision, then this can result in artificially low warning and alarm limits.

Two limits are set on the control charts, which are (i) a warning limit to show that the CEM is starting to drift out of control and (ii) an action or alarm limit to show that the CEM has drifted beyond specifications and corrective actions are needed.

Whilst auto-corrections before the CEM drifts out of the control range are not recommended, such auto-corrections may take place so long as the CEMs still meet the MCERTS specification for zero and span drift. The QAL3 is then a test that the system is remaining under control in the operating environment, particularly if the whole sampling system is tested by the QAL3 and the auto-corrections are based on the analyser performance only.

Rather than performing complex calculation by combining uncertainties, the French national standards body AFNOR proposes a simpler approach based on a fraction of the uncertainty specified in applicable Directives (Table 3). This approach has shown to produce similar results to the approach of combining uncertainties.

Table 4 – AFNOR method for calculating S_{AMS} for WID installations

Determinand	Uncertainty allowance	DA ELV in mg.m^{-3}	S_{AMS} in %	S_{AMS} in mg.m^{-3}
CO	10	50	2	1
NO _x	20	200	2	4
SO ₂	20	50	2	1
TOC	30	10	3	0.3
HCl	40	10	10	1
HF	40	1	20	0.2
Particulate	30	10	10	1

Operators may also develop their own control charts and limits based on experience. However, generally more complex control charts are more sensitive at detecting changes, whilst more zero and span measurements will also result in a greater degree of control. Lastly, the procedure for determining the upper and lower limits on Exponentially Weighted Moving Average Charts differ from those used for CUSUM and Shewhart charts (see section 4.3.4).

4.2 Zero and span checks

Zero and span checks shall be performed using several means and reference materials, such as test gases for gas-monitoring CEMs and filters for particulate monitors. If this is not practicable or possible, then the CEMs supplier may provide surrogates such as filters which should be traceable to national standards in the case of gases. In the case of particulates, due to the complex sizes, shapes and behaviour of particulate matter, there is no true surrogate for this determinand for use in the field. However, any surrogate which remains constant for a given, known period of time (ideally at least a year) may be suitable for span measurements under QAL3.

4.2.1 Test gases and reference materials

If test gases are used, then such gases used should be traceable to primary National Standards and should have certificates which meet the requirements of ISO 6142. Test gases are required for all the gaseous determinands with ELVs, unless the operator or CEMs supplier can demonstrate a linear relationship between the drift effects of different determinands. Such a relationship would have to have a correlation coefficient of the regression line of at least $R^2 = 0.99$.

Gas-mixing systems can be used, as these are particularly useful for multi-point span checks. Such systems should meet the performance standards specified in USEPA Method 205.

Surrogate reference materials are required for performing zero and span checks on particulate monitoring CEMs and these should be assessed as part of the MCERTS testing for their validity in providing an appropriate QAL3 check. However, it is permissible to use surrogates and alternative devices such as filters or electronic simulations of particulate matter, as long as these have been validated during the MCERTS testing for QAL1.

In terms of span gas concentrations, there are no firm rules on the actual concentrations. However, a good starting point is to use a span gas which has a concentration of 80% to 100% of the half-hourly ELV. It should be noted that the higher the concentration, the more sensitive the span check to changes, whether these are random variations or systematic changes due to actual drift. Therefore the values for the warning and action limits may need to be changed to take into account the greater sensitivity to changes, when using higher concentrations of span gases.

4.2.2 Requirements on the CEMs and data recording systems

To carry out zero and span checks, the CEMs and the data recording systems have to be able to:

- record both positive and negative values
- record any changes in readings from the previous zero and span checks
- record zero and span data results for greater than one year. This permits auditing of the data at the AST.

4.2.3 Frequency of checks

If operators are using CUSUM charts (see next section), then weekly zero and span checks will be required. If operators are using Shewhart charts, then the frequency may be based on the maintenance interval determined during testing for MCERTS certification, although we recommend using shorter intervals until sufficient data is available to lengthen the time between checks.

Users have the option to use instruments with either automatic or manual QAL 3 checks. The majority of instruments use automatic self-checks since these tests can be conducted without additional work from personnel.

4.2.4 Adjustments to span readings

Once the CEM has been calibrated and passed the QAL2 tests, the initial span readings are used to set the baseline for the control charts. In the past, it has been usual to make adjustments to the span setting if span checks show a difference between the original span level, and the most recent span check – this is especially the case when service engineers perform calibration checks during routine services. However, these minor adjustments to zero and span settings of the CEM must not be carried out unless several span readings are outside the action limits set within the control charts. In other words, if the span readings are

within the action and alarm limits on the control charts, then no action is required and the CEM should not be adjusted.

Note: Some types of CEMs have automated zero and span functions, together with small automatic adjustments. This approach is acceptable if the CEM was tested and certified using this approach, and if the applied auto-corrections are recorded.

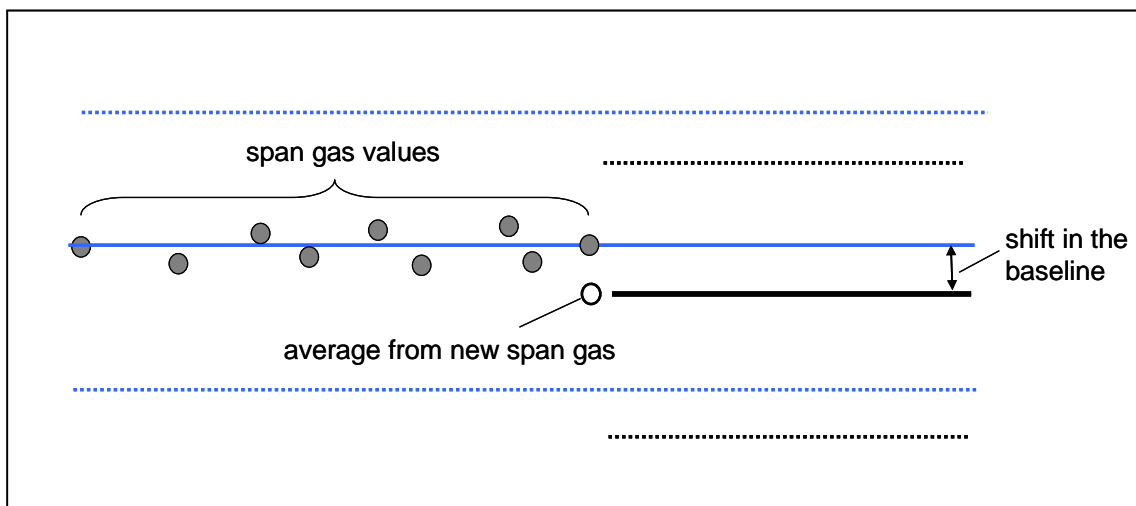
4.2.5 Replacing gas bottles or other surrogates

When replacing gas bottles, differences in the concentrations of bottles may mislead an operative into believing that the CEM has drifted. This is because two gas bottles with seemingly identical contents can produce different readings in a CEM because of the uncertainty of the concentrations. This results in a step change in the CEM readings when the one bottle is changed for another. Hence it is important to differentiate and account for such step changes, instead of mistaking such changes for drift. Therefore when changing gas bottles, the following steps are recommended:

- (a) Take at least five span readings with the current gas bottle, and then take an average of the readings.
- (b) If the span readings using the current gas bottle show that the CEM has not drifted beyond the action limits since the last span readings, then go to Step (d).
- (c) If the CEM has drifted, then carry out any necessary actions to remedy this; then proceed to Step D.
- (d) Take at least five span measurements using the replacement span-gas bottle, and then set a new baseline for the control-chart span-level using an average of the five measurements.

Sets of readings with an existing bottle, followed by an equal number of readings with a second bottle, will establish the magnitude of any step-changes (Figure 10).

Figure 10 – Shift in the baseline following a change of span-gas bottles



4.2.6 QAL3 checks and Article 13 of the WID

The WID specifies availability requirements for CEMs; for a daily average value to be valid, an operator may discard no more than five half hourly average values in any day due to

malfunction or maintenance of a CEM. This includes periods when the CEMs are out of calibration or conducting zero and span checks.

However, for practical purposes, we consider that 20 minutes in any given half-hourly period is representative of a half-hour monitoring period. Therefore operators do not have to invalidate the daily average value if:

- there are no more than five half-hourly periods with less than 30 minutes of valid data, although more incomplete periods may be permitted provided that the operator can justify this, and;
- the half-hourly periods contain at least 20 minutes of valid data;
- operators do not have to stop loading waste at WID installations during zero and span checks, providing that the operators still comply with the above and the requirements of Article 13 of the WID, as laid down in the permit.

4.3 Use of control charts

EN 14181 specifies the use of control charts for QAL3 and describes two types of control chart, Shewhart charts and CUSUM charts. The latter are more complex, but provide more information on the performance of the CEM. Shewhart charts, for example, will only show whether there is drift, whereas the procedure described for CUSUM charts in EN 14181 will also determine whether there are changes in the precision of the CEM, as well as any drift. Other types of control charts may also be used, however, such as exponentially weighted moving average charts.

4.3.1 Purpose of control charts

Under QAL3 the operator regularly checks the response of the CEM to zero and span reference materials. If these readings are repeated over a sufficiently short period of time – and the CEM has not had a chance to drift – then the actual readings will be due to variations in precision and allowable effects of influence quantities. Over a period of time, as the operator collects more data, there is only a very small chance that the readings will change by more than three standard deviations, unless the CEM has truly drifted. The purpose of control charts is to plot such trends and give an indication of actual or forthcoming drift.

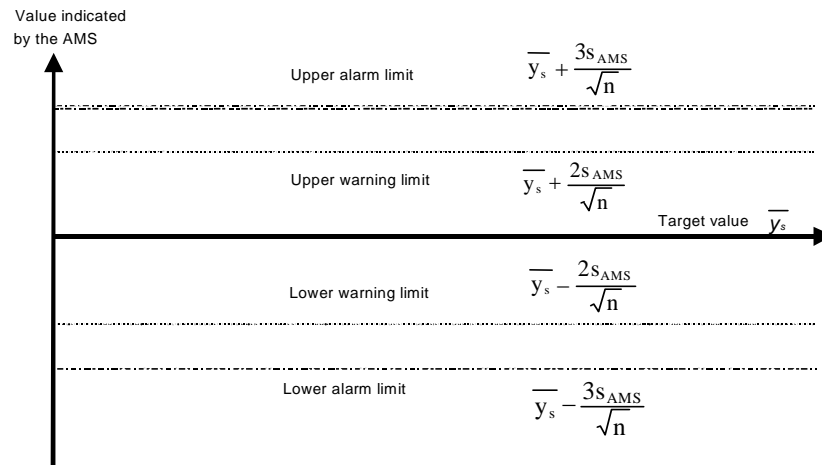
The user either calculates or determines the standard deviation, s_{AMS} for the operation of the instrument under anticipated stack conditions and then uses multiples of this standard deviation to set warning levels and alarm (or intervention) levels. Two control charts are needed – one for zero drift and one for span drift. There is a choice to use either the manufacturer's specifications on uncertainty or alternatively the maximum allowable uncertainty as defined in the MCERTS performance standards.

4.3.2 Shewhart control charts

The results are presented as a function of time. The values shown by the CEM can be expressed as an absolute value or as the difference between the reading and the expected value of the reference material. Two control charts are needed – one for zero drift and one for span drift. Figure 11 shows an example template for span drift.

The target values on the two charts are the average value of zero and span readings, \bar{y}_z and \bar{y}_s established during the initial QAL3. This should be carried out immediately after the QAL2 has been completed. The associated standard deviations s_{AMS} and s_{AMS} are used to calculate the levels which will trigger an alarm and possible intervention.

Figure 11 – Example template for Shewhart Control Charts



The upper and lower warning levels are given by $\bar{y}_s + \frac{2s_{AMS}}{\sqrt{n}}$ and $\bar{y}_s - \frac{2s_{AMS}}{\sqrt{n}}$

The upper and lower alarm limits are given by $\bar{y}_s + \frac{3s_{AMS}}{\sqrt{n}}$ and $\bar{y}_s - \frac{3s_{AMS}}{\sqrt{n}}$

where n is the number of consecutive repetitions of the test carried out (n should be at least 10 for the initial QAL3 but can be equal to one in the case of a repeat QAL3)

Once the control chart is set up, the results of the zero and span tests (averages of the n readings on the CEM) are placed on the chart in order to detect drift and/or changes in precision that require intervention by the operator e.g. maintenance of the CEM and possible rejection of the results since the previous tests.

EN 14181 requires the operator to intervene when:

- one or more data points are beyond one of the upper alarm limits;
- three consecutive data points are beyond one of the warning limits;
- four points among five consecutive ones are beyond $\bar{y}_s \pm \frac{s_{AMS}}{\sqrt{n}}$ i.e. half the alarm levels for span;
- eight consecutive points are on the same side of the mean, unless the points are within $0.5 s_{AMS}$;
- six consecutive points are either increasing or decreasing.

4.3.3 CUSUM charts

Any limitation that the Shewhart chart has in detecting progressive changes or staged changes can be overcome by associating several successive control points, i.e. through the use of moving mean charts such as CUSUM control charts. To achieve this, the values calculated and entered on the chart are not the last value but the average of several previous values.

The CUSUM, or *cumulative sum* chart uses all of the data and is therefore a more sensitive way to detect slight changes in the mean. If a target value C is being considered, then the operating principle of the chart is to calculate the difference between each new value and value C , and to add this to a cumulative sum. This cumulative sum is then reported on the chart relative to the values measured.

As long as the measurement results are close to the target value, the CUSUM chart's curve remains close to zero. A positive curve indicates that the results are greater than the target value and a negative curve shows the opposite. Stepped changes in a data series is shown by an abrupt change in curve shape. A gradual drift produces slight but continuous changes in the mean.

4.3.4 Exponentially Weighted Moving Average Charts (EWMA)

Exponentially Weighted Moving Average (EWMA) charts are an alternative to either Shewhart or CUSUM charts. There are two ways to improve the detection of slow and gradual changes in the precision and accuracy of the AMS, due to drift. These are to:

- increase the number of checks, since efficiency increases with \sqrt{n} , but this will produce a cost that increases proportionally to n . Also increasing the number of checks will also decrease the availability of the CEM;
- take into account the previous results.

EWMA charts or CUSUM charts improve the efficiency of detection by using results of measurements previous to the last check, whereas Shewhart charts do not. Compared to the Shewhart chart, the EWMA chart:

- is more appropriate for early detection of small or medium-sized drift;
- is simpler and easier to use than the CUSUM chart;
- is easier to set up and keeps the graphical format of the Shewhart chart;
- implements only one decision rule;
- reduces the risks due to the natural variability of the process and helps to avoid useless questioning as to the random changes in this process.

This chart requires three preparatory steps:

Selecting the decision criteria: $n = 1$; $\delta\sqrt{n} = 1$; $\sigma_0 = s_{AMS}$; ARL, maximum ARL; L and λ

Determining weighting of the past values with the last reading:

$$z_i = \lambda x_i + (1 - \lambda) z_{i-1} \quad (1)$$

where

z_i is the weighted average taking the past and the last check into account;
 x_i is the AMS reading for the last check;

and $0 < \lambda < 1$.

In order to determine the control limits:

$$UCL = m_0 + L \frac{\sigma_0}{\sqrt{n}} \sqrt{\frac{\lambda}{2 - \lambda}} \quad (2)$$

$$LCL = m_0 - L \frac{\sigma_0}{\sqrt{n}} \sqrt{\frac{\lambda}{2 - \lambda}} \quad (3)$$

The control limit value L and the smoothing parameter λ are selected so as to obtain an Average Run Length (ARL) that is set as a quality objective. This ARL is the average number of successive checks required to detect a δ maladjustment, that may be a false alarm if the process is not maladjusted.

The Maximum Average Run Length (Max ARL) is the maximum number of successive checks required to detect a δ drift, if the process is maladjusted.

If λ nears 0, this will take the past more into account and detect small drifts, but sudden major drifts are less easily detected.

If λ nears 1, this will take the past less into account and responsiveness to sudden major drifts are greater, but small drifts will be less easily detected.

If a slow drift is expected, select a λ near 0,25, but if sudden changes are expected then select λ near 0,5.

In order to simplify the choice of EWMA chart decision criteria, where $n = 1$ and $\sigma_0 = s_{AMS}$, let $\lambda = 0,35$ and $L = 2,9445$, which produces an ARL of 11,7 (12) and a maximum ARL of 29. In comparison, the Shewhart chart with $\lambda = 1$ and $L = 3$ produces an ARL of 370 for $\delta\sqrt{n} = 0$, or 44 for a $\delta\sqrt{n} = 1$ with a maximum ARL of 130.

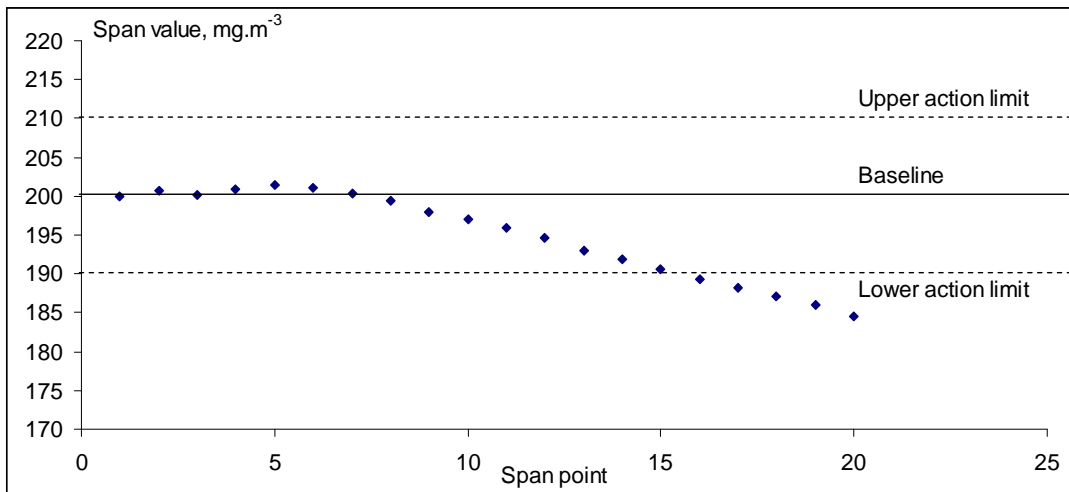
This means that for the same set of data from an AMS, a Shewhart chart will require 44 successive checks to detect a problem compared with only 12 for the EWMA chart. An estimated 130 checks is required for the Shewhart chart compared with a maximum of 29 for the EWMA chart. Table 4 shows the values of the span checks which were used in the example of a Shewhart chart, together with the weighted, smoothed values.

Table 5 — Raw and calculated EWMA data

Span check number	Span value mg/m³	EWMA value mg/m³
1	200	200,0
2	202	200,7
3	199	200,2
4	202	200,8
5	203	201,5
6	200	201,0
7	199	200,3
8	198	199,5
9	196	198,0
10	195	197,1
11	194	196,0
12	192	194,6
13	190	193,0
14	190	191,9
15	188	190,6
16	187	189,3
17	186	188,2
18	185	187,1
19	184	186,0
20	182	184,6

Figure 12 shows the EWMA chart. When compared to the Shewhart chart, acceptable random variations are smoothed, whilst the systematic changes are much clearer to see. It should be noted that only one upper control-limit and one lower control-limit are required.

Figure 12 - Example of an EWMA chart



4.4 Reporting

QAL3 records should include the following:

- CEM details – monitoring approach and technique, operating range, make and model
- CEM changes – details of change in make, model and serial number through the year
- manufacturer's service visit records – routine maintenance
- manufacturer's call out records – corrective actions taken
- operator's routine maintenance and corrective actions
- QAL3 baseline re-sets - summary
- zero and span drift plots
- zero and span drift tabulation

5 Annual surveillance test (AST)

5.1 Purpose of the AST

The Annual Surveillance Test (AST) is a mini-QAL2 whose purpose is to verify the continuing validity of the calibration function. In general the key points in section 3 also apply to the AST.

5.2 Functional tests

The requirements and responsibilities for carrying out the AST tests is the same as for QAL2 (see sections 3.4 and 3.5). The testing laboratory has overall responsibility for the functional tests, although either the operator or the equipment supplier may perform these. In such cases, these tests shall be verified by audit by the accredited testing laboratory and included in their report.

5.3 Parallel measurements with a SRM

Only the testing laboratory may perform the SRMs. It must be noted that five tests are a minimum and that the testing laboratory is advised to carry out a greater number in case any tests are deemed invalid.

If the test laboratory is using instrumental methods for SRMs, then the SRM monitoring-system may be operated continuously during the AST tests. Zero and span checks on monitoring systems used within SRMs shall take at least at the start and the end of the monitoring period, and at least once every 24 hours. Test laboratories shall state in their Site Specific Protocol the time intervals between the start-time of each pair of measurements. Furthermore, test laboratories shall demonstrate that the interval between each pair of data provides representative samples, taking into account any process variations.

Note: For example, due to process and/or safety constraints, a test laboratory may only be able to take data at certain times. This may occur during a batch process. In such cases, the test laboratory may leave an instrumental SRM running, but still perform the zero and span checks once every 24 hours. In such cases, it is essential to ensure that the measurements are still representative, and that the SRM is stable over a 24 hour-period.

Any continuous monitoring systems used within SRMs shall be certified where possible to the MCERTS performance standards for CEMs.

6 Status of this guidance

This TGN may be subject to review and amendment following its publication. The latest version can be found on our web-site at: www.environment-agency.gov.uk by typing M20 into the search facility.

We also welcome feedback on its use. Any comments or suggested improvements to the TGN should be e-mailed to Richard Gould at richard.gould@environment-agency.gov.uk

References

1. EN 14181. Stationary source emissions – Quality assurance of automated measuring systems.
2. BS EN 13284-2. Stationary source emissions – Determination of low range concentration of dust – Part2: Automated measuring systems.
3. Directive 2000/76/EC, on the incineration of waste.
4. Directive 2001/80/EC, on limiting emissions of certain pollutants into the air from large combustion plants.
5. BS EN ISO 14956. Air quality — Evaluation of the suitability of a measurement procedure by comparison with a required measurement uncertainty.
6. Performance Standards for Continuous Emission Monitoring Systems – The Environment Agency’s Monitoring Certification Scheme (MCERTS), www.mcerts.net.
7. EN 15267-3 Air quality — Certification of automated measuring systems — Part 3: Performance criteria and test procedures for automated measuring systems for monitoring emissions from stationary sources.
8. TGN M1. Sampling requirements for monitoring stack emissions to air from industrial installations. Environment Agency.
9. Method Implementation Document (MID 15259) for BS EN 15259:2007, Stationary source emissions – Requirements for the measurement sections and sites and for the measurement objective, plan and report
10. BS EN 13284-1. Stationary source emissions — Determination of low range mass concentration of dust — Part 1: Manual gravimetric method
11. BS EN ISO 9001. Quality management systems – Specification with guidance for use.
12. BS EN ISO 14001. Environmental management systems - Specification with guidance for use.
13. BS ISO 10012. Measurement management systems — Requirements for measurement processes and measuring equipment.
14. BS ISO 11095. Linear calibration using reference materials.
15. TGN M2. Monitoring of stack emissions to air. Environment Agency.

Annex 1 – Additional guidance on the functional tests

EN 14181 specifies within QAL2 and the Annual Surveillance Test (AST) that CEMs must have a set of annual functional tests. The exact requirements for these tests are described in Annex A of EN 14181. This annex explains the requirements for the functional tests. Our position is that there are no restrictions on which organisation can perform the functional tests, as long as there is evidence to demonstrate that:

- the tests shall at least meet the requirements of Annex A of EN 14181;
- the organisations performing these tests should include appropriate procedures within their management systems, to provide for the functional tests;
- there are other provisions for quality assurance applied to the functional tests, to demonstrate that the tests are performed to an appropriate degree of quality assurance.

In this annex, the term *organisation* refers to the party which performs the functional tests.

A1 Responsibilities

A1.1 Safety

Process operators, CEMs suppliers and test laboratories need to perform safety risk-assessments before starting the functional tests. Any required corrective actions needs to be carried out before the functional tests, in order to ensure a safe working area, where all applicable hazards are either eliminated, or the risks of such hazards are reduced as far as practicable.

Process operators are responsible for ensuring that the functional tests specified in EN 14181 are performed at least annually, and should not be performed more than one month earlier than the parallel reference tests required by the QAL2 and AST parallel reference tests required by EN 14181. If the parallel reference tests are performed more than one month after the functional tests, then the operator must demonstrate that the functional tests are still valid; for example, QAL3 data may provide sufficient evidence. The test laboratory must document this evidence on the QAL2 or AST report, as applicable.

The functional tests may be performed by either process operators, test laboratories or suppliers of continuous emission monitoring systems (CEMs), taking into account the guidance in this document. Furthermore, the test laboratories are responsible for reporting the results of the functional tests.

Note: It is risky to perform the parallel reference tests without having performed and validated the functional tests beforehand. Furthermore, the functional checks are a mandatory requirement of EN 14181.

A1.2 Quality assurance of tests

We recommend that any organisation performing, managing or reporting the functional tests does the following:

- includes procedures for the functional tests within a documented management system
- uses Annex A of EN 14181 and this document as a basis for the procedures.

A2 Procedures for the functional tests

A2.1 Scope of the functional tests

Table A1.1 specifies the individual parts of the functional test of AMS to be performed during QAL2 and AST for extractive and non-extractive AMS. All these functional tests shall be performed.

Table A1.1 – Functional tests

Activity	QAL2		AST	
	Extractive CEM	Non-extractive CEM	Extractive CEM	Non-extractive CEM
Alignment and cleanliness		✓		✓
Sampling system	✓		✓	
NOx converter efficiency	✓		✓	
Documentation and records	✓	✓	✓	✓
Serviceability	✓	✓	✓	✓
Leak test	✓		✓	
Zero and span check	✓	✓	✓	✓
Linearity			✓	✓
Interferences			✓	✓
Zero & span drift (audit)			✓	✓
Response time	✓	✓	✓	✓
Report	✓	✓	✓	✓

We recommend that the linearity and interferences tests (where applicable) are also performed before the parallel reference tests for the QAL2, as well as before the parallel reference tests for the AST.

Additionally, it is essential to review historical data before carrying out the functional tests and parallel reference tests, in order to evaluate normal instrument operation and details of process peaks.

If the sampling system is equipped with a NOx converter, then the operator needs to ensure that the efficiency of this converter is tested at least once per year, more frequently if the manufacturer of the converter specifies more frequent checks, and the efficiency must not be less than 95%.

A2.2 Alignment and cleanliness

The organisation shall make a visual inspection of the CEM, with reference to the CEM manuals, on the following items when applicable:

- internal check of the analyser
- cleanliness of the optical components
- flushing air supply

- obstructions in the optical path.

After re-assembly at the measurement location at least the following shall be checked:

- alignment of the measuring system – this can be checked with reference materials, e.g. filters
- contamination control (internal check of optical surfaces)
- flushing air supply.

The organisation performing the tests shall record the results in a test report.

A2.3 Sampling system

The organisation shall make a visual inspection of the sampling system, noting the condition of the following components, when fitted:

- sampling probe
- gas conditioning systems
- pumps
- all connections
- sample lines
- power supplies
- filters
- if applicable, check that heated sample-lines are operating at the correct temperature.

The sampling system shall be in good condition and free of any visible faults, which may decrease the quality of data.

If the sampling system is equipped with a NO_x converter, then the operator needs to ensure that the efficiency of this converter is tested at least once per year, more frequently if the manufacturer of the converter specifies more frequent checks, and the efficiency must not be less than 95%.

A2.4 Documentation and records

The operator is required to either have, or have access to the following documentation. The organisation shall assess whether the following documentation is controlled, readily accessible and up to date. A complete audit is not required, but simply a compliance check to ensure that the following documentation is in place.

- a plan of the CEM
- all manuals (maintenance, users, etc.)
- log books to document possible malfunctions and action taken
- service reports
- QAL3 documentation including actions taken as a result of out of control situations
- management system procedures for maintenance, calibration and training
- training records
- maintenance schedules

- auditing plans and records – evidence that the operator includes the procedures for the management of the CEMs within the auditing cycle of the management system;
- existing instrument calibration functions/gain factors;
- documentation and records audit completed and validated prior to commencing SRM testing.

A2.5 Serviceability

EN 14181 requires operators to provide provisions for the effective management and maintenance of the AMS, in order to ensure the maintenance of the quality of data. Such provisions include at least the following:

- safe and clean working environment with sufficient space and weather protections, with reference to a valid platform inspection certificate;
- easy and safe access to the AMS (personnel and equipment);
- adequate supplies of reference materials, tools and spare parts.

In order to conduct the tests effectively, in addition to the requirements for testing the CEM, and the requirements for the sampling location and the working platform which are required for QAL2 and QAL3, facilities shall be provided to introduce the reference materials, both at the inlet of the sampling line (where present), and at the inlet of the analyser.

The signals from the analyser through to the digital control system or data logger need to be checked and confirmed.

The organisation needs to record compliance with the above requirements, and recommend improvements if appropriate.

A2.6 Leak test

The organisations shall assess extractive CEMs for leaks, according to the CEM manuals and applicable standards for monitoring. The test shall cover the entire sampling system.

The response time and leak test could be covered at the same time by injecting one gas (SO₂ or CO₂) directly into the probe.

A2.7 Zero and span check

Reference zero and span materials shall be used to verify the corresponding readings of the CEM. In case of non-extractive CEMs, zero and span checks shall be performed using a reference-path free of flue gas before and after readjustment.

As a cross reference, test laboratories should conduct a separate span on the operator's CEM with their own traceable gases.

A2.8 Linearity

a. procedure

Ordinarily, the linearity of the analyser's response shall be checked using five different reference materials, including a zero concentration. The reference material with zero concentration, as well as the reference materials with four different concentrations, shall have a verifiable quantity and quality.

Note: The linearity test may be performed on the analyser alone, provided that there is a test with the highest concentration of the test gas, through both the entire sampling system, and then the analyser. This specific application of the linearity test may be combined with the tests for leaks, losses in the sampling line, response time and lag time.

In case of gaseous reference materials, these four reference materials can be obtained from different gas cylinders or can be prepared by means of a calibrated dilution system from one single gas concentration.

The reference material concentrations shall be selected such that the measured values are at approximately 20%, 40%, 60% and 80% of the range of two times the emission limit. It is necessary to know the values of the ratios of their concentrations precisely enough so that an incorrect failure of the linearity test does not occur. The dry test reference material shall be applied to the inlet of the CEM.

The individual analysers are tested using the following concentrations applied in a randomised sequence:

- reference material with zero concentration;
- reference material concentration approximately 20% of 2 times the emission limit;
- reference material concentration approximately 40% of 2 times the emission limit;
- reference material concentration approximately 60% of 2 times the emission limit;
- reference material concentration approximately 80% of 2 times the emission limit;
- reference material with zero concentration.

After each change in concentration, the first instrument reading shall be taken after a time period equal to at least three times the response time of the CEM. At each reference material concentration, at least three readings shall be made. The time period between the start of each of the three readings should ideally be separated by at least four times the response time. A time period of less than four times response time may be used as detailed in MID EN14181.

Note 1: This procedure means that the quality of the reference material may influence the result of the tests. It should be noted, however, that it is the result that leads to a pass or failure in the test. In some cases, a reference material with a higher quality may change the result from fail to pass.

Note 2: Special care should be taken, when handling HCl or HF in dry gases. For example, particular surface reactions in tubing can result in a very long response time, which is not representative of the response time for humid gases.

Note 3: Where no other method is possible, the linearity can also be performed with the aid of reference materials such as grating filters or gas filters. The linearity shall be calculated and tested using the procedure as given in annex B in EN 14181. If the AMS does not pass this test, then the problem shall be identified and rectified.

If CEM values can only be logged manually during linearity testing digital control system trends and logged values could be utilized and incorporated into the report to show that adequate stability had been achieved and to help validate each of the points obtained.

b. meaning of 'emission limit value'

Ordinarily, EN 14181 refers to the daily average ELV. This would ordinarily apply to the linearity test, since the performance of the CEM is compared with the original performance

specifications, which are typically expressed as percentages of a certification range. This certification range in turn is a multiple of the daily average ELV.

However, there is a strong benefit in testing the linearity of the CEM at higher values, especially those based on the short-term ELV. For example, the ELV could be a half-hourly ELV as specified in the Waste Incineration Directive (2000/76/EC). Therefore those performing the linearity check may base the test range on the short-term ELV, whilst applying the same performance criteria for the linearity test based on the daily-average ELV.

c. Test gases

Test gases shall be traceable, where possible, to ISO 17025 for calibration by third party accreditation from a nationally recognised accreditation body, that is a member of the International Laboratory Accreditation Cooperation (ILAC). The test gases shall be labelled with the relevant accreditation logo and number.

A2.9 Interferences

If the AST fails the calibration or variability test, a test shall be undertaken if the process gases to be monitored contain components that are known interferences, as identified during QAL1.

The manufacturer/test house when conducting span/linearity tests with each specific gas/gases should report zero responses on all other components.

A2.10 Zero & span drift (audit)

The test laboratory shall assess whether the operator has a QAL3 procedure in place, and whether the operator has applied this procedure. The evidence would comprise (i) a documented procedure, (ii) zero and span data, (iii) control charts.

A2.11 Response time

The response time of the CEM shall be checked. This can be performed, if appropriate, by feeding of the reference material at the end of the sampling probe. The organisation performing the check needs to note the length of the sample line if the CEM is an extractive system. When the results of this test are compared to the results of the same span gas fed directly into the analyser, the differences in response times is the lag-time due to the length of the sampling system. This information needs to be taken into account when the test laboratory performs the parallel reference tests required by the QAL2 and AST of EN 14181, in order to align the responses of the CEMs and SRMs.

A2.12 Report

The results of the functional test shall be reported. Any faults shall be recorded. If the faults are judged to have an effect on the quality of data, then the operator shall carry out the necessary corrective and preventive actions.

The functional test shall be supplied, assessed and validated before to conducting the parallel reference tests required by QAL2 and the AST. Any necessary corrective actions should be addressed before the test laboratory performs the parallel reference tests.

Annex 2 - k_v values and t-factors

Table A2.1

Number of parallel measurements N	$k_v(N)$	$t_{0.95}(N-1)$
3	0,8326	2,353
4	0,8881	2,920
5	0,9161	2,132
6	0,9329	2,015
7	0,9441	1,943
8	0,9521	1,895
9	0,9581	1,860
10	0,9629	1,833
11	0,9665	1,812
12	0,9695	1,796
13	0,9721	1,782
14	0,9742	1,771
15	0,9761	1,761
16	0,9777	1,753
17	0,9791	1,746
18	0,9803	1,740
19	0,9814	1,734
20	0,9824	1,729
25	0,9861	1,711
30	0,9885	1,701

Ordinarily between three and eight pairs of data are required for an AST, and at least 15 measurements for a QAL2. If there are more than eight pairs of data for an AST, or more than 30 for a QAL2, then it is advisable to choose the applicable k_v and $t_{0.95}$ values for the next lowest value. For example, if there are 37 pairs of data points, then k_v and $t_{0.95}$ values for 30 data pairs can be safely used.

Glossary

Glossary of terms	
AST	Annual surveillance test
CEM	Continuous emission monitoring system
CI	Confidence Interval
ELV	Emission Limit Value
LCPD	Large Combustion Plant Directive
QA	Quality assurance
QAL	Quality assurance level
SD	Standard deviation
SRM	Standard reference method
UKAS	United Kingdom Accreditation Service
WID	Waste Incineration Directive